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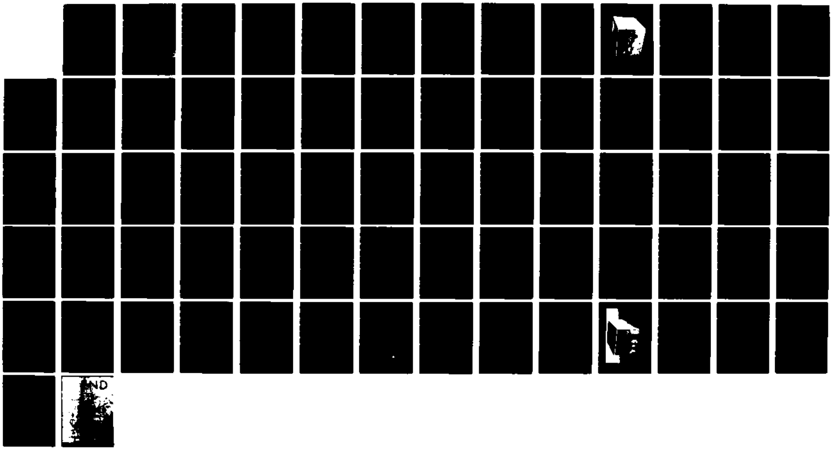

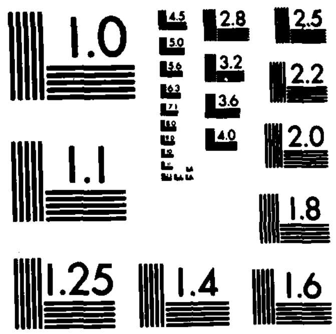

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TASK REPORT
MIL-STD-1553B DATA BUS AUDIO INTERCOM SYSTEM

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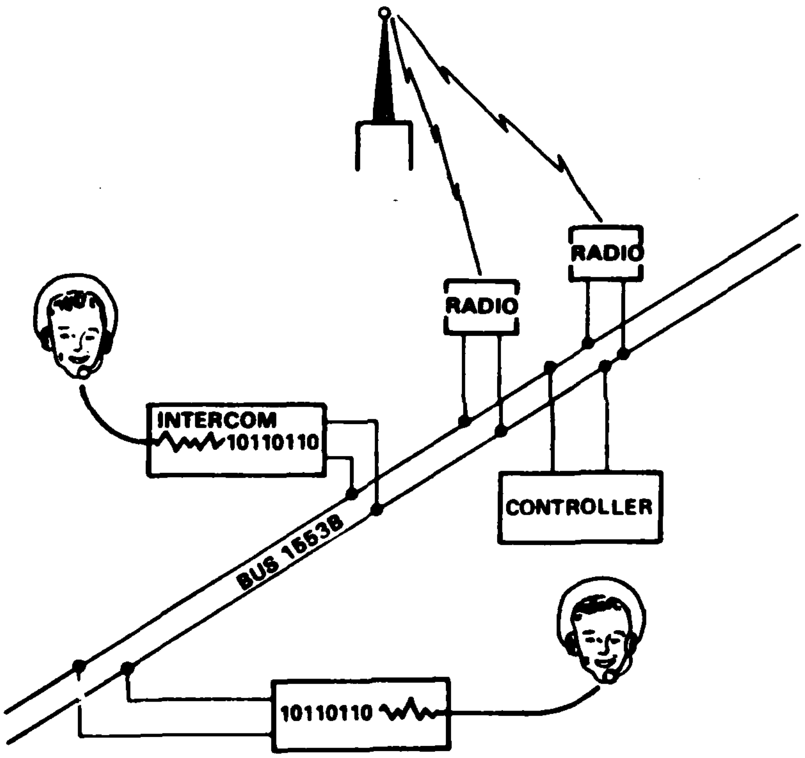

Prepared for

Naval Air Development Center
Warminster, Pa

Contract No. N62269-79-C-0075

AIRESEARCH MANUFACTURING COMPANY
OF CALIFORNIA

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MIL-STD-1553B DATA BUS AUDIO INTERCOM SYSTEM

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GARRETT

AIRESEARCH MANUFACTURING COMPANY
OF CALIFORNIA

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1. INTRODUCTION

The MIL-STD-1553B multiplex data bus system offers a common means of interconnecting subsystems in military aircraft avionic systems. Presently the 1553B data bus structure accommodates the control, status, and data type of signals that comprise 80 to 90 percent internal interface exchange between avionic equipment. However, as a tool for overall avionic systems integration, this system can be used to implement integrated control and display panels, various processing architectures, and provide the ability to access the total avionic systems for monitoring status, built-in test, and diagnostics. Provisions for growth and modification are an inherent part of the design.

The key feature of the MIL-STD-1553B system is its flexibility. The system can be utilized in total or in part to satisfy a particular interconnectivity requirement. In effect the system interrogator manipulates the system to satisfy his interface signal exchange by implementing the type of signal routing and bus control that is best suited to his needs. This is done within the constraints of a common protocol and data bus structure.

Under contract No. N62269-77-C-0236 to NADC, (April 5, 1979) AiResearch further exploited the flexibility of the 1553A data bus by developing a multiplex aircraft intercom system that demonstrated the ability of 1553 protocol and format to accommodate audio signals for exchange between crew members and radio equipment.

The system designed and developed by AiResearch was first demonstrated at the Second Multiplex Data Bus Conference sponsored by the Air Force System Command on October 10 through 12, 1978. Subsequently the system was delivered to NADC's BASIC Laboratory for systems feasibility demonstration and test and for experimentation when operating on a common data bus mixed with avionics data. To date the system has been operating at NADC as in integral subsystem within the BASIC Laboratory.

The significance of this earlier development effort was the demonstration that a 1553 data bus could accommodate audio signals and therefore could be considered for future affiliation with military aircraft, either as an addition to an existing avionics data bus or as a dedicated audio bus system. (See NADC evaluation Report 4092TM-BASIC-001.) The subject report addressed the incorporation of strict MIL-STD-1553B (dated September 1978) protocol within the developed audio multiplex intercom system as well as the flexibility offered by the system relative to aircraft implementation.

To this end, this report addresses the implementation of the existing Rockwell/Collins CMS-80 cockpit management system as a totally integrated control navigation IFF (CNI) control and audio data bus system. The potential of utilizing and implementing speech recognition and synthesis technology can be the subject of further study as the technology matures.

Appendix A summarizes the significant areas of MIL-STD-1553B. A more detailed description of this program and the earlier demonstration program are presented in Appendix B.

2. SUMMARY

The purpose of this report is not to define the technology of the audio multiplex system, but to study the protocol and the mode of operation to be utilized.

The present study defines the audio multiplex system such that it will satisfy MIL-STD-1553B. This system is based on an earlier demonstration system delivered to NADC as part of the contract No. N62269-77-C-0236.*

The technology utilized in the earlier demonstration system for the bus interface and the transformation of the voice into digital information was satisfactory. However, the control will be changed to work with the new protocol described in this report. (The new system utilizes a 1553B dual bus and a dual bus controller to satisfy the redundancy needs.)

The audio terminals (AT's) can be controlled by a specially designated bus controller, or a controller designed as part of an existing cockpit management system. As an example, the CMS-80 system developed by Collins already operates with a 1553 bus system, and a minor modification of the software would allow the Collins bus controller to control the AT's. It would be highly desirable that a wholly integrated cockpit management system would include AT's, as it already includes the tuning of the radio communication channels. These possibilities will be discussed in the system description (Section 3, para. 3.7).

The system described in this report defines an AT able to realize normal conversion and broadcast, as well as an option for conference calls between three persons. The bus may be connected to the radio channels aboard the airplane.

The option "restricted conversation" allows the information to be scrambled between terminals and controlled by the bus controller (BC); the scrambling of the digital information before being reconstituted into voice by the continuously variable slope delta modulator (CVSD) system ensures a high degree of restriction if such a condition is desired.

The first demonstration system (Figure 2-1) is built around the following two integrated circuits:

(a) The MC3417 integrated circuit from Motorola transforms the voice by CVSD and reconstitutes the voice from the digital data.

*This earlier system is described in AiResearch reports 79-15855 and 79-16283.

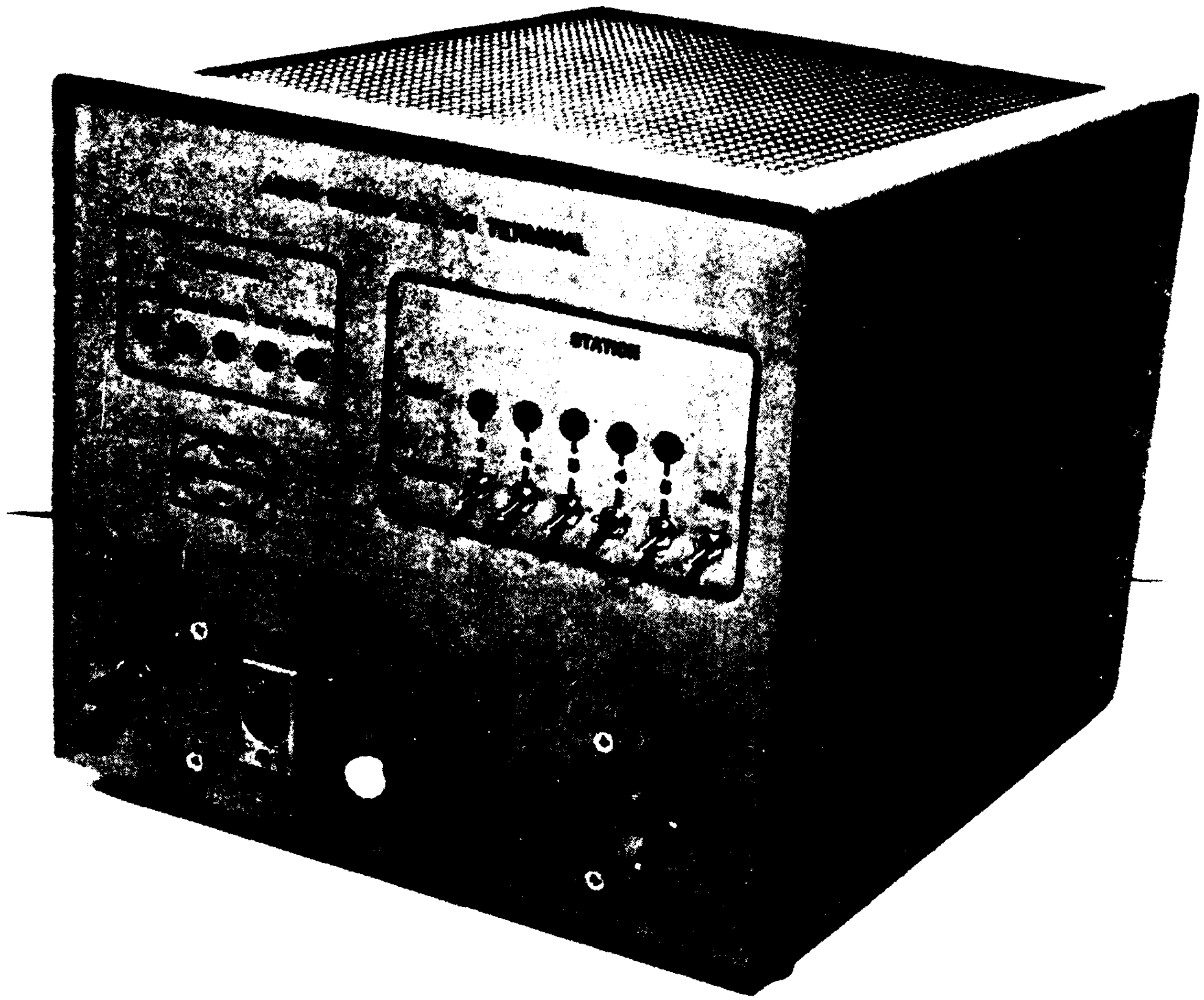


Figure 2-1. Audio Multiplex Intercom System (ICS) Terminal (NADC Contract N62269-77-C-0236)

(b) The HD-15531 integrated circuit from Harris provides the interface to the data bus for sending words with the formats required by 1553, including the SYNC signal and the computation of the parity bit.

These two circuits have been described in AiResearch report No. 79-15855, and have operated satisfactorily in the AiResearch demonstration system since delivery. Both are still the basic circuits of the terminal presented in this report.

3. GENERAL BUS OPERATION

The proposed system operates in a MIL-STD-1553B mode where the bus controller (BC) polls the stations and determines which stations have to receive and which have to transmit. The BC initializes the transfers, and then monitors the activity on the bus to detect faults.

The protocol described in this report is analyzed to determine the efficiency, the rate of decodification of the voice, and the different options the system may include to handle a great number of audio terminals (AT's), or to handle voice and data transmission on the same bus.

The audio multiplex system realizes the interconnection of several AT's localized in an aircraft (i.e., at short distances) by a digital bus. The voice is transformed to digital information by a continuous, variable-slope delta (CVSD) modulator and the digital information is retransformed into audible information by a CVSD demodulator. The operating principles of the CVSD and the integrated circuit that perform this function have been described in AiResearch report 79-15855 (NASD contract N62269-77-C-0236).

The digital information is serialized and sent to the bus by time division multiplexing. The control of the time given to each source is realized by a BC. Several BC's and several buses are used for redundancy.

3.1 BUS EFFICIENCY

The transmission time of a message of n words, as shown in the lower part of Figure 3-1 is:

n words + 7 words + 3 response time + 2 gaps with: 1 word = 20 μsec 1 response time = 12 μsec; 1 gap = 10 μsec. Message transmission time = (n x 20 + 196) μsec. The efficiency will be measured by the ratio between time of effective data and total time.

$$\text{Efficiency} = \frac{n \times 16}{n \times 20 + 196}$$

For 1 word transmitted, efficiency = 7.4 percent

For 16 words transmitted, efficiency = 49.6 percent

For 32 words transmitted, efficiency = 61.2 percent

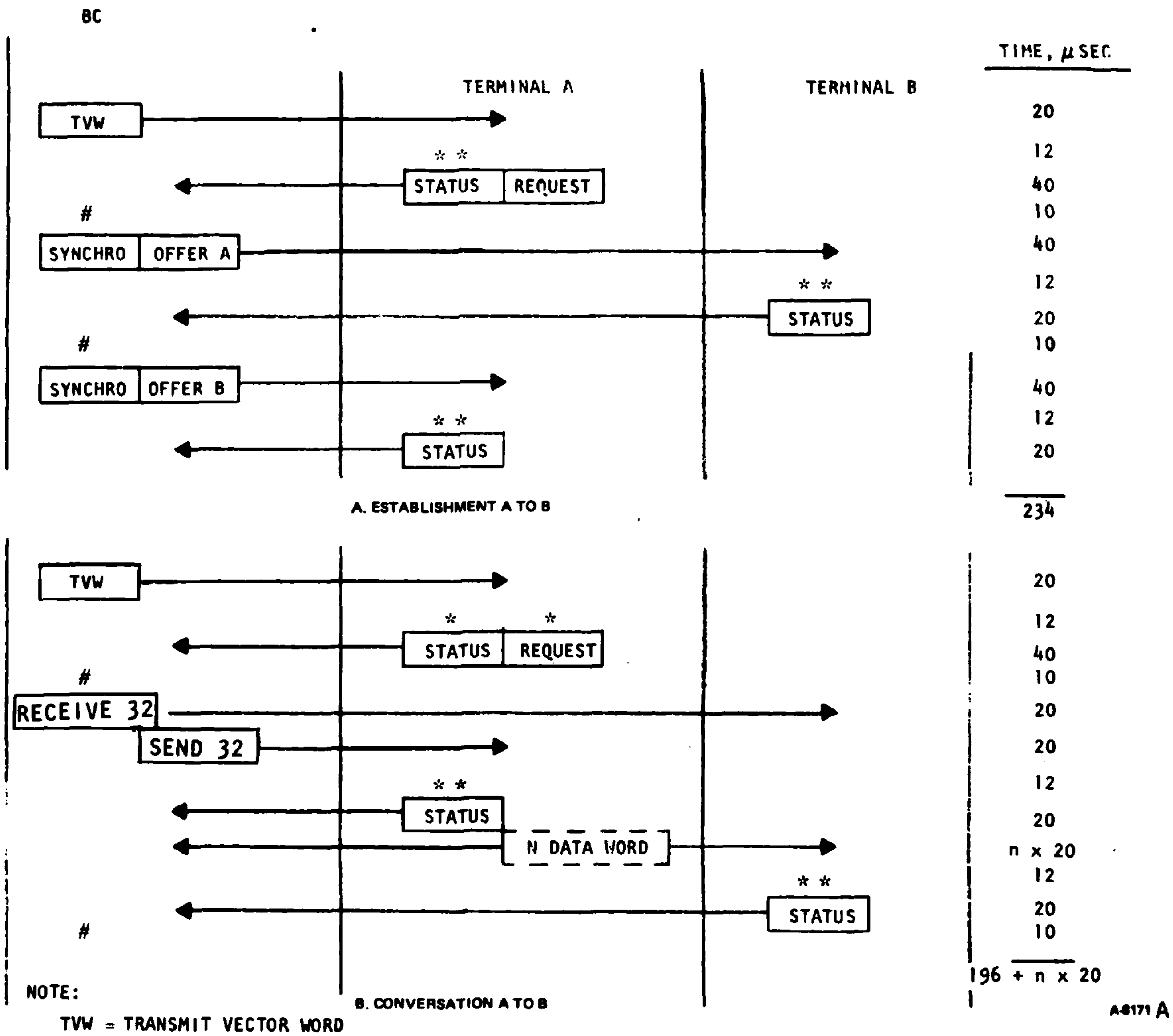


Figure 3-1. Conversation Between A and B

NOTE: The efficiency of the system can be much improved by utilizing longer messages. For 64 words, efficiency = 84 percent. For 128 words, efficiency = 91 percent. The tri-service data bus committee on 1553B could consider the possibility of sending more than 32 words per message in applications for on audio multiplex system, should such efficiency be desired by aircraft avionic system integrators.

Since the length of a message is limited to 32 words by the 1553B specification, 61.2 percent is the highest value of efficiency attainable with the protocol defined in this report. In voice transmission, the minimum transmission time is several seconds. One second of speech at 50,000 bit/sec (CVSD decodification rate) generates about 3,000 words (about 100 complete messages of 32 words). The efficiency of the system will be close to the 61.2 percent if the system is designed to manage complete messages (32 words) in a conversation.

3.2 BUFFER SIZE

For the reasons stated above the minimum size of a buffer will be 32 words, and the polling system will consider that a terminal has to transmit when the number of words is equal or higher than 32 words. But supposing a terminal is polled when the buffer is almost ready (32 words - ε)* and that the management of the bus is correct (total polling time = time to create 32 words by an audio converter), the next time the terminal will be polled may occur when the buffer has 32 - + 32 = 64 words - ε. This determines the capacity of the buffer: the size of the buffer (in or out) of an AT has to be 64 words of 16 bits. There is no need for a greater size.

3.3 POLLING TIME

The time to fill and empty a buffer depends on the decodification rate of the CVSD system (modulator or demodulator). The earlier demonstration system could operate with two different rates (R):

R = 50,000 bits/sec, which means 3,125 words of 16 bits/sec.

R = 25,000 bits/sec 1,562.5 words/sec.

The quality of the voice depends on this rate, and can be defined as:

(a) Excellent of 50,000 bits/sec

(b) Good at 25,000 bits/sec

(c) Fair at 16,000 bits/sec

Since the terminals are interrogated one by one (polling) and supposing each terminal has to transmit a full message (32 words) the time to poll terminals is:

$$T_{poll\ max} = N \times (32 \times 20 + 196)\ \mu sec = N \times 836\ \mu sec$$

* ε = small quantity

The minimum polling time is obtained by considering the first three words of the establishment (no conversation to establish).

$$T_{poll}\ min = N\ (3 \times 20 + 1\ gap + 1\ response\ time) = N \times 82\ \mu sec$$

The maximum polling time has to be smaller than or equal to the time required to empty a buffer of 32 words; otherwise the CVSD may decode undefined information. This time is

$$T_{decode} = \frac{32 \times 16}{R}$$

The equation: Tpollmax = Tdecode, gives the following table:

R	50,000	25,000	16,000
Tdecode, μsec	10,240	20,480	32,000
Tpollmin, μsec	984	1968	3116 **
N	12	24	38 *

* = Limited to 31 by MIL-STD-1553B
** = Limited to 2542 μsec

3.4 INTEGRATION WITH CMS-80 SYSTEM

The CMS-80 cockpit management system developed by Collins includes two data buses, and two bus controllers (BC's). The BC's are able to poll terminals in a 1553A mode and the exchange of information is made from terminal to controller (and vice versa). This system is well adapted for data transmission where there is practically no transferfrom remote terminal to remote terminal, and where the load on the bus is presently from 15 to 20 percent. For an audio multiplex system, the protocol described in this report should be implemented in the Collins BC's; this can be achieved by a minor modification of the existing CMS-80 control software.

3.5 OPTIONS

3.5.1 Rate Switching

Even if the system includes many terminals, it is not probable that everybody will be talking constantly; even if everybody is engaged in conversation, it is not common to talk and listen at the same time, so that the number of transmissions is usually divided by 2. In a system with 30 terminals, the assumption can be made that, most of the time, less than 12 terminals will be emitting, and that consequently the rate of decodification of the voice can be set to 50,000 bits/sec in order to achieve a excellent quality of the voice. To allow the system to handle the maximum traffic, the rate of decodification of the voice can be switched from one value to the other. The way this "rate switching" can be achieved is explained in the protocol description (para. 4.2.1).

3.5.2 Restricted Conversation

The reception of a conversation by a terminal depends on the detection of the address contained in the command words and on proper ordering of overall 1553B protocol (see Figure 3-2). Thus, a terminal cannot listen to a conversation between two other terminals.

The restrictiveness of a conversation on the bus can be reinforced in sending the words from the buffer of the emitting remote terminal (RT) to the receiving RT by incorporating a scrambled, random-order sequence unknown to any other listener. For instance:

(a) The BC elaborates a table of random bits.

(b) From time to time, the BC updates an equivalent table in the RT by sending information that cannot be sent externally. For example, via the SYNC signal: command SYNC = 1, data SYNC = 0. The procedure follows a special command that indicates to the RT's that the 32 following words have to be taken as data words (which can be used to transmit other synchronizing data) regardless of the SYNC; the successive sync values are stored in a special table.

(c) When a message is sent, the order in which the words are sent and received follows an algorithm based on the bits in the table.

This procedure does not require a lot of time and can be standardized in internal communications.

3.5.3 Mode Without BC

A mode of transmission can be conceived without a BC. This can be a degraded mode that is implemented within any RT equipped with a system to monitor a BC failure. This procedure could save the implementation of a backup BC in an installation with a low-redundancy requirement, or it could constitute a second backup in installations with two BC's. The procedure may be set as follows:

- The detection of a long silence (100 μsec for instance) on the bus sets all terminals in AUTO-MODE. Then, after a period depending on the address, (i.e., a 10 μsec address) the RTo sends a command word which indicates to all RT's that RTo is in control. This command word is followed by a transmission procedure if RTo wants to emit, or by end of transmission. The second terminal takes over, and then performs a transmission (or end transmission), etc. until the last terminal is reached. After 30 μsec, RTo reiterates its operation, and so on. During the last 30 μsec of each cycle, the BC can take over if the fault has disappeared.

The above operational sequences describe 1553B data bus manipulation that could enhance overall system operation depending on the particular application of the audio multiplex system. The system is flexible enough to manipulate restrictive conversation, priority level management, and other desired features and options.

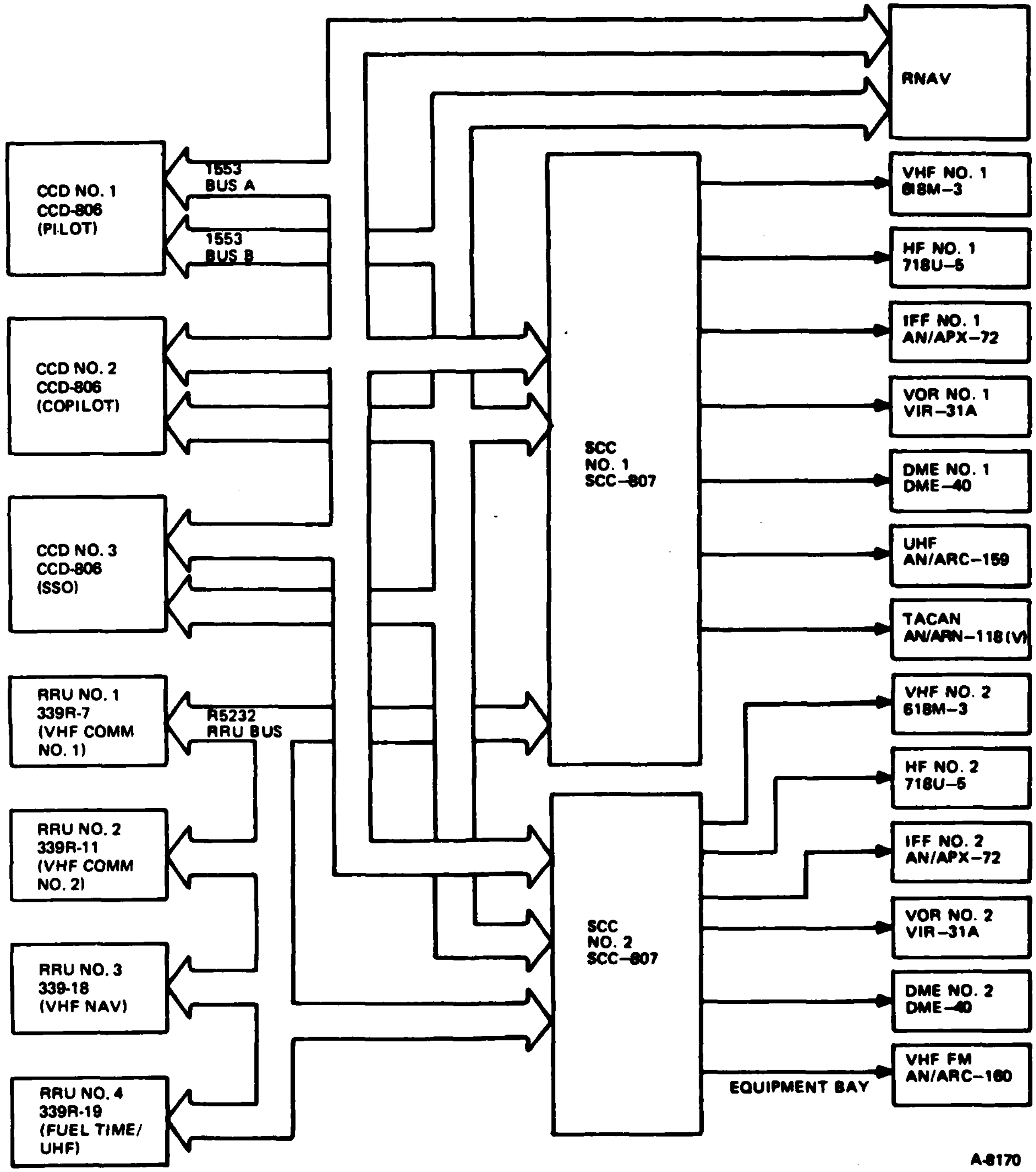


Figure 3-2. CMS-80B Cockpit Management Systems, System Interface

3.6 SYSTEM DESCRIPTION

An audio multiplex system is defined by the number of terminals and bus controllers. The system has to offer a high level of reliability, which means a certain degree of redundancy as follows:

Multibus--A second bus seems to be the minimum requirement of redundancy in a system that requires a high level of security. Bus transmission to a particular terminal will be declared invalid when the following events occur:

Short-circuit: no data received, or level of signal too low, generating a high rate of errors.

Open circuit: generates a high rate of errors

Interface invalid: information is sent on the bus when it should not, information is not sent when required, or a high rate of errors is generated (parity, sync, word invalid, bad status, etc.).

Multicontroller--A terminal can be invalid without affecting the operation of the rest of the system. But if the BC does not function properly, the whole system is affected. This is because the BC initializes all the transfers and supervises the operation of each terminal. The systems presented in this report are equipped with two BC's.

3.6.1 Stand-Alone System

The system presented in this report comprises of two data buses, two BC's, five audio terminals; and radio channels. The radio channels are not tuned by the audio terminals, but by an external system. Only one controller and one bus are active at a given time, the other bus and the other BC are used as backups. Figure 3-3 shows the system with five audio terminals (AT's) and six radio channels.

3.6.2 System with Cockpit Management System

The system can be connected to the Collins CMS-80 system if the Collins controllers are modified to satisfy the requirements of the AT as shown in Figure 3-4, the system includes:

- Two bus controllers (listed as SCC's 1 and 2 in Figure 3-2)

- Three cockpit control displays (CCD)

- Five AT's

- Six radio channels: VHF1, VHF2, HF1, HF2, UFF, VHF-FM

The tuning of the radio channels is performed by the CMS-80 system through the integrated cockpit control/display panel(s). The existing radios must be connected to a 1553B adaptor. This adaptor may be shared by several radios, as shown on the Figure 3-4.

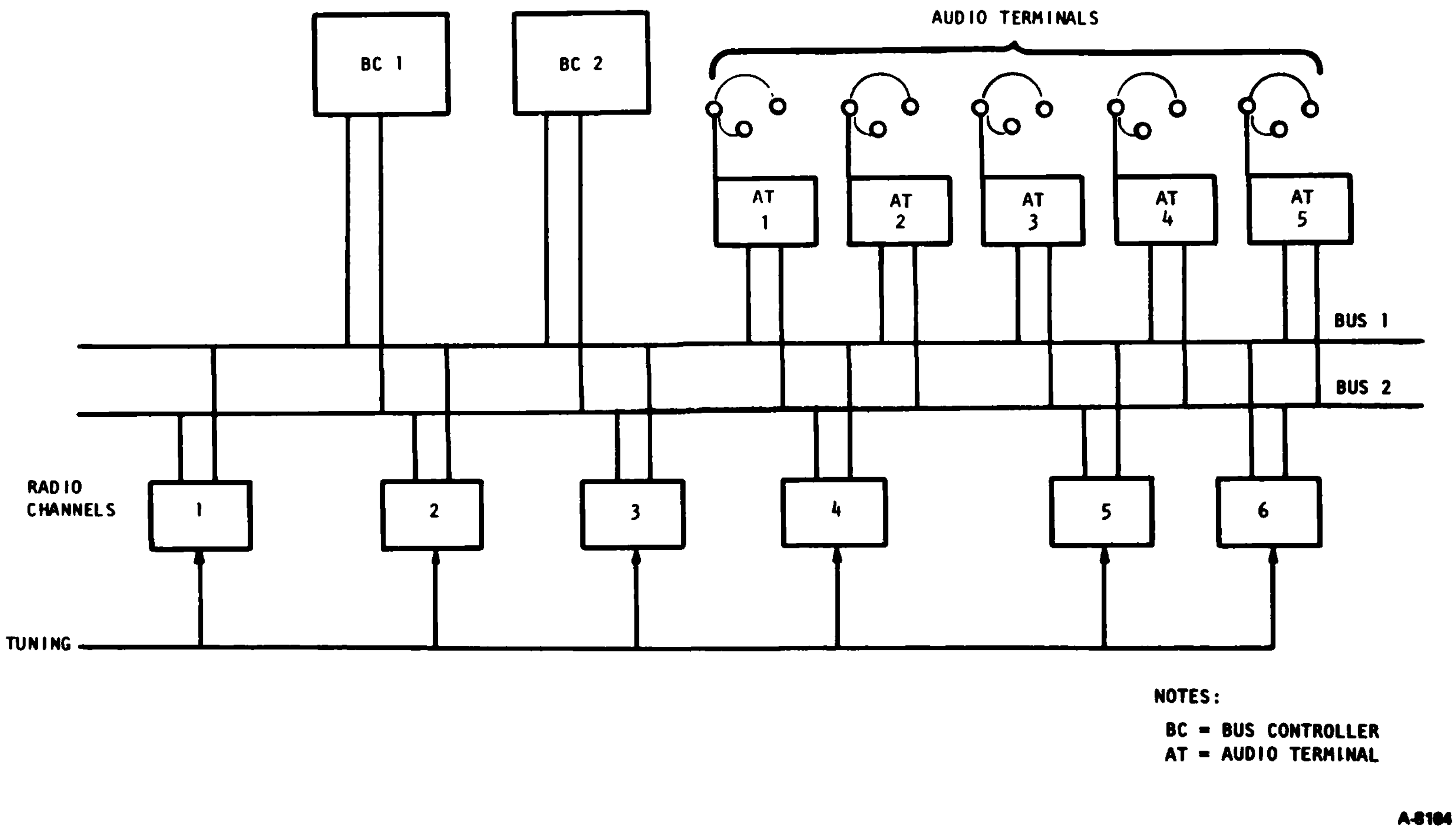


Figure 3-3. Audio Multiplex General Diagram for Five Audio Terminals and Six Radio Channels

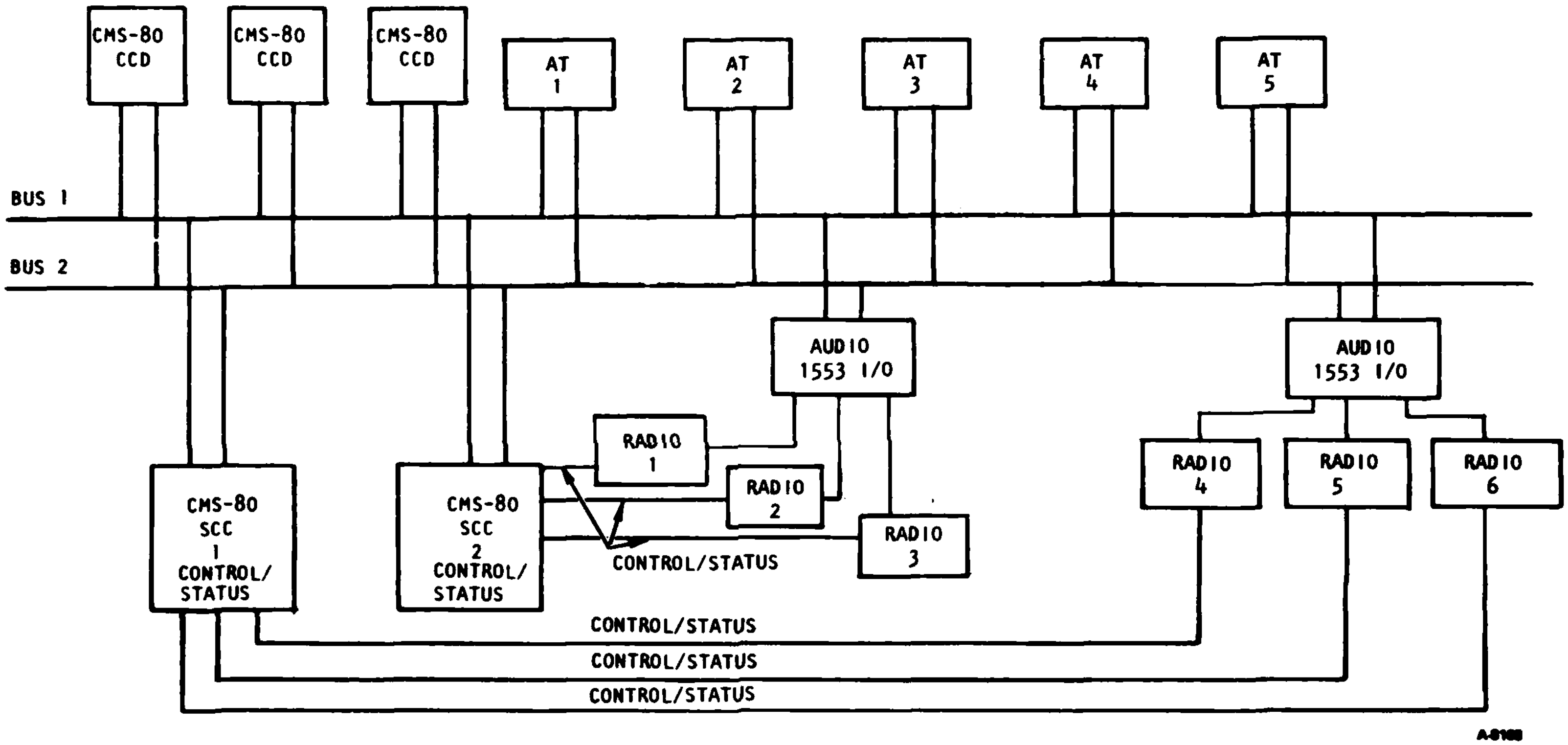


Figure 3-4. Audio Multiplex System Integrated With CMS-80 in Which Existing Radios Require External Audio 1553B Adaptor Box

Analysis of the Collins CMS-80 system indicates the traffic of their system utilizes the bus for less than 20 percent of the time. The communication system defined in this report determines an absolute efficiency higher than 60 percent in data transmission. Thus, the initial rate of 1,000,000 bits/sec (MIL-STD-1553B) allows a useful rate of 480,000 bits/sec for the terminals, including the radio channels. For the eleven terminals shown in Figure 3-4, this rate allows each terminal to send 43,600 bits/sec (the rate of the voice decoder). For this system, there is no need to implement the rate-switching option since this rate is sufficient to ensure a very good quality of voice.

3.6.3 Tuning by Bus

A third system with the CMS-80 can be conceived, in which all transmissions, including the tuning information to the radio channels, would transmit by the bus. This would include a greater modification of the CMS-80, but would save some hardware. This system is represented in Figure 3-5. The CMS-80 can be replaced by the mission computer if this computer can provide the functions of bus control and system tuning.

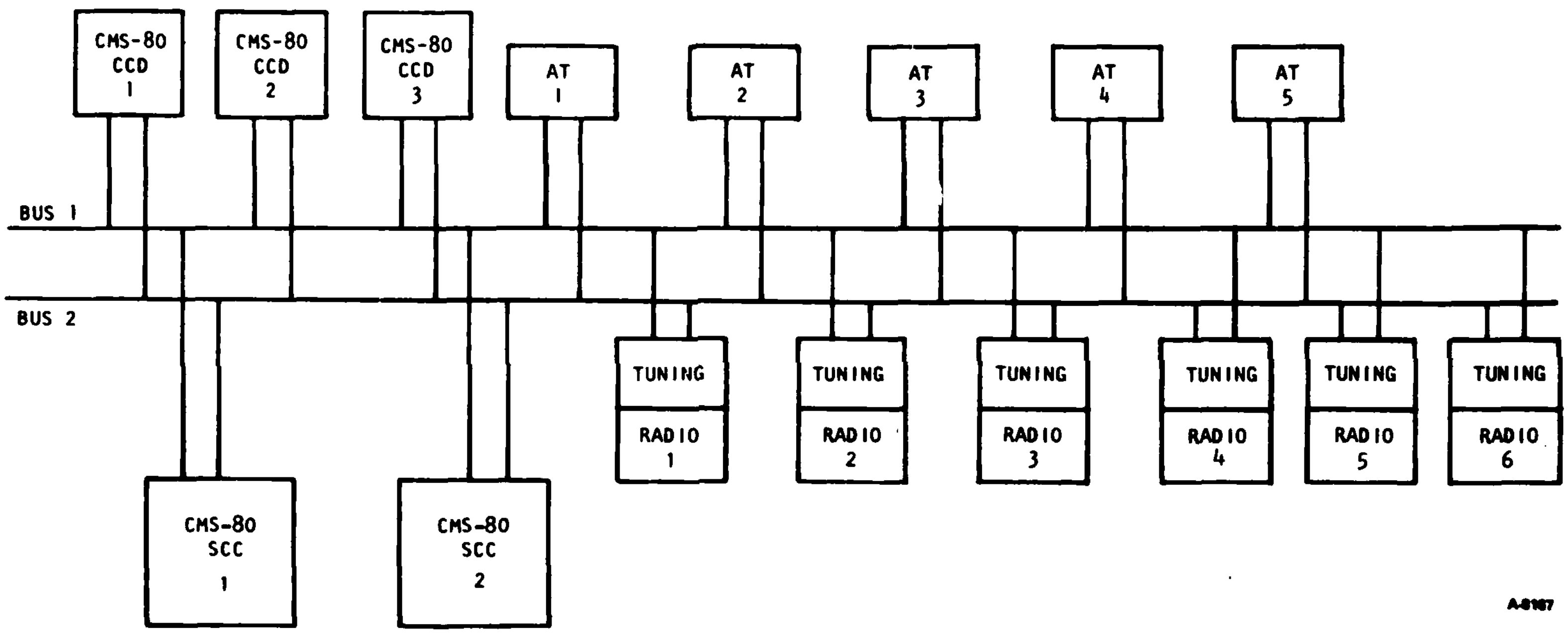
3.6.4 Variations

The systems represented herein are typical systems. They may include:

(a) Greater or fewer of terminals (the rate of the CVSD circuit has to match the traffic requirement)

(b) Avionic interfaces exchanging data, i.e., the CMS may include a RNAV system with a navigation computer unit (NCU) and a control display unit (CDU).

(c) Terminals using a different protocol, providing the BC's can handle different protocols.



NOTE:
MISSION COMPUTER(S) ALSO CAN PROVIDE THE FUNCTIONS OF BUS CONTROL AND SYSTEM TUNING

Figure 3-5. System No. 3: CMS-80, Audio Multiplexer with Direct Tuning by Bus

4. PROTOCOL

This system operates in a MIL-STD-1553B mode. The bus controller (BC) polls the stations and determines which stations have to emit and which have to receive. It then initializes and checks the transfers in monitoring the faults. The operations are as follows:

- The BC sends a command word to the first terminal. This terminal responds with a status word and a data word that indicates if the terminal has to transmit, the number of words (from 1 to 32), the terminal to which it wants to transmit, and a number of indications (complementary status bits).
- If the terminal does not require any bus operation, the BC addresses the next terminal.
- If the terminal requires an emission and there is no other activity pending on the bus (i.e., priority data), the BC initializes the transmission by sending command words to the terminals interested in the operation.
- In a simple transmission from RT to RT, the BC sends the command: "Emit n data w" to the emitter.
- In a broadcast mode, the BC sends the command "broadcast receive n data w" to the RT's defined as receivers. This is followed by a command "transmit n data w" to the emitter.
- When the exchange is terminated, the BC determines which operation takes place next, and generally interrogates the next terminal.

4.1 COMMAND WORDS UTILIZED FOR THE TRANSMISSION

The audio multiplex system utilizes the words defined by the MIL-STD-1553B and reproduced Figure 4-1. Every sequence of transmission is started by a command word from the BC. The protocol uses the following command words:

Transmit Vector Word--Used with one data word. The answer is a status word and a request data word. This command word is used to poll the terminals to determine if they are busy, requesting that a conversation be established, or have a message to be transmitted.

Synchronize--Followed by one data word (offer) to establish a conversation with a terminal (called the TO terminal) when another terminal (FROM terminal) requests the conversation. Synchronize is also utilized to send command tones, for which the offer data word has a special format (see tone description, para. 4.2.6).

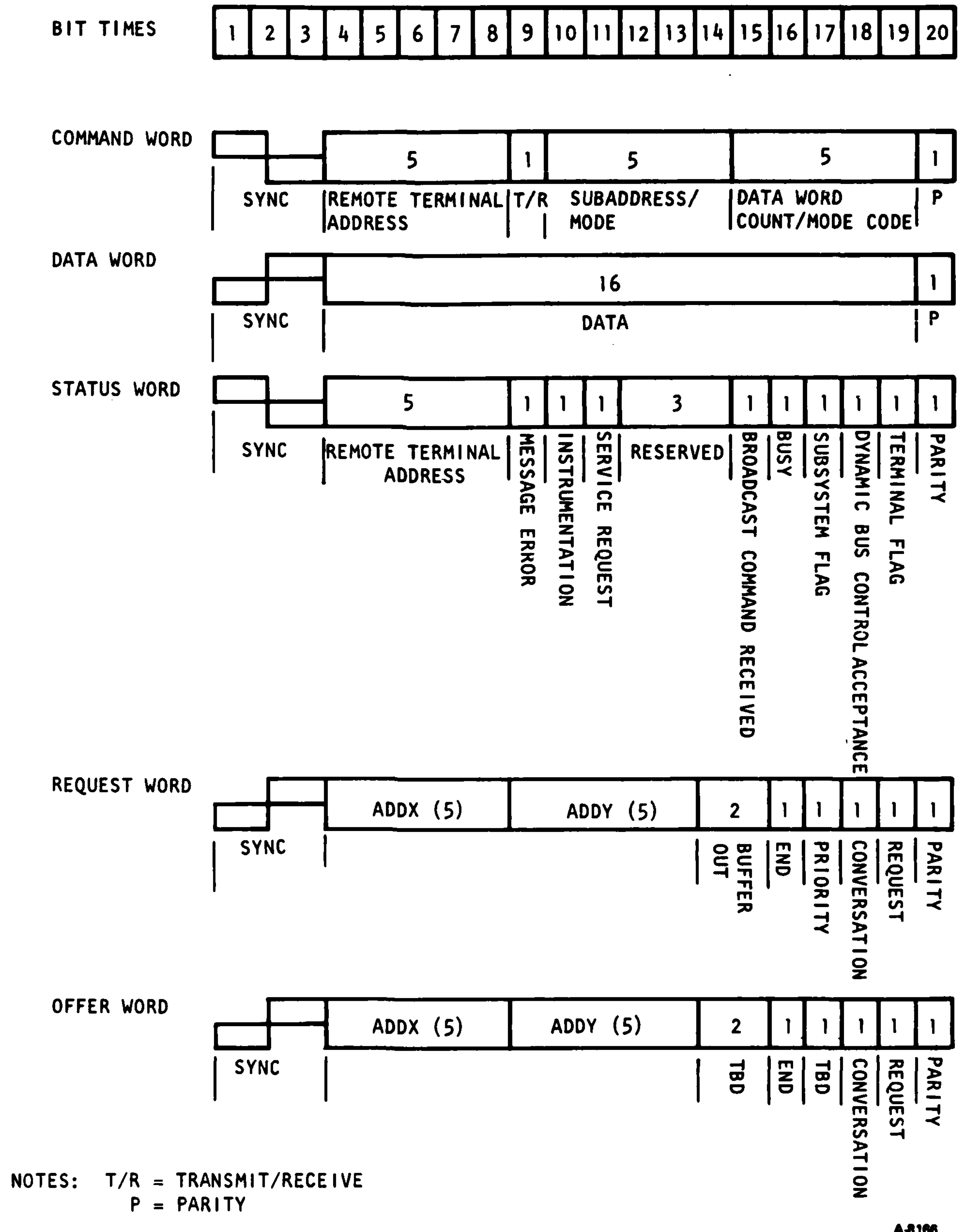


Figure 4-1. Word Formats

Transmit Status Word--Utilized at the end of a broadcast communication because the status cannot be sent automatically by several terminals at the same time.

Except for the commands designed for systems with more than two buses, the system utilizes all the commands given in the 1553B specification. These are listed in Table 4-1. The following description of the conversations illustrate the protocol.

4.2 CONVERSATION

When a crew member wants to establish a conversation with another person, he selects the corresponding position on an ICS control panel. The BC transmits the request to the TO terminal. If the TO terminal is busy, a lamp blinks on both panels, indicating the busy status to the FROM station, and notifies the TO station of the calling station. (A warning tone to the TO station is an option.) If the TO terminal is not busy, the two lamps are lighted on the two panels and the communication is established.

Since the status word cannot contain information upon conversation request, a REQUEST WORD is used for this purpose. The REQUEST WORD presented in this report is only a model. The place of each bit may be different in the application.

4.2.1 REQUEST WORD

The REQUEST WORD contains complementary information needed by the BC to initialize and control a transfer between terminals. The status word only indicates if the terminal is busy (bit 16) and contains a service request bit (bit 11) to be used by exception. The request word contains the following fields:

ADDX: between 00000 and 11110 or 11111 (broadcast) address of the terminal with which the conversation is to be established - channel 0

ADDY: option between 00000 and 11110 or 11111 for one conversation only. The address of the second terminal in case the conversation is to be established between three terminals--channel 1

REQUEST BIT: R, indicates that the operator pushed a button on his keyboard, requesting a conversation to be established with another crew member.

BOUT: (two bits) Indicates the status of the BUFFER OUT and the action to be taken by the BC:

00 = less than 31 words: ignore transfer

01 = from 32 to 47 words: transfer 32 words

TABLE 4-1

ASSIGNED MODE CODES

Transmit/ Receive (T/R) Bit	Mode Code	Function	Associated Data Word	Broadcast Command Allowed
1	00000	Dynamic bus control	No	No
1	00001	Synchronize	No	Yes
1	00010	Transmit status word	No	No
1	00011	Initiate self test	No	Yes
1	00100	Transmitter shutdown	No	Yes
1	00101	Override transmitter shutdown	No	Yes
1	00110	Inhibit terminal flag bit	No	Yes
1	00111	Override inhibit terminal flag bit	No	Yes
1	01000	Reset remote terminal	No	Yes
1	01001	Reserved	No	TBD
	↓	↓	↓	↓
1	01111	Reserved	No	TBD
1	10000	Transmit vector word	Yes	No
0	10001	Synchronize	Yes	Yes
1	10010	Transmit last command	Yes	No
1	10011	Transmit BIT word	Yes	No
0	10100	Selected transmitter shutdown	Yes	Yes
0	10101	Override selected transmitter shut-down	Yes	Yes
1 or 0	10110	Reserved	Yes	TBD
	↓	↓	↓	↓
1 or 0	11111	Reserved	Yes	TBD

Note: TBD = To be determined

			BOUT	E	Pr	C	R	
NO REQUEST	X	X	0 0	0	0	0	0	P
REQUEST TO B	ADDB	-0-	-0-	0	0	0	1	P
TRANSFER 32 to B	ADDB	-0-	0 1	0	0	0	0	P
TRANSFER 16 + 32	ADDB	-0-	1 0	0	0	0	0	P
TRANSFER 28 + 32	ADDB	-0-	1 1	0	0	0	0	P
END	ADDB	-0-	0 0	1	0	0	0	P
PRIORITY REQUEST	ADDB	-0-	0 0	0	1	0	1	P
REQUEST TO B and C	ADDB	ADD C	0 0	0	0	1	1	P
BROADCAST	1 1 1 1 1	-0-	0 0	0	0	0	1	P
SPECIAL	1 1 1 1 1	1 1 1 1 1						P

BOUT = BUFFER OUT
E = END
Pr = PRIORITY
C = CONFERENCE
R = REQUEST

A-8161

Figure 4-2. Request Word: Different Status

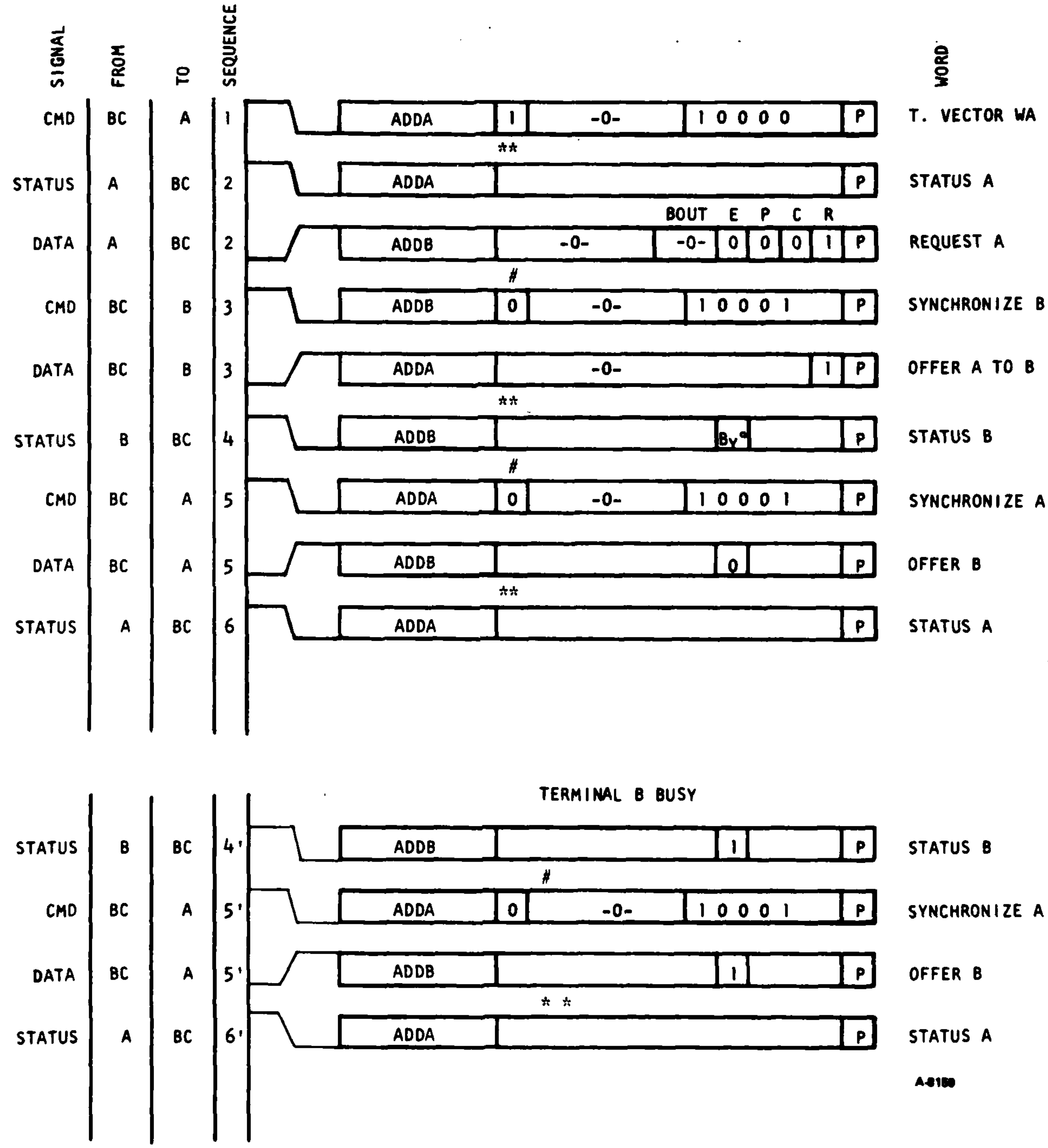


Figure 4-3. Establishment of Normal Conversation From Terminal A to Terminal B

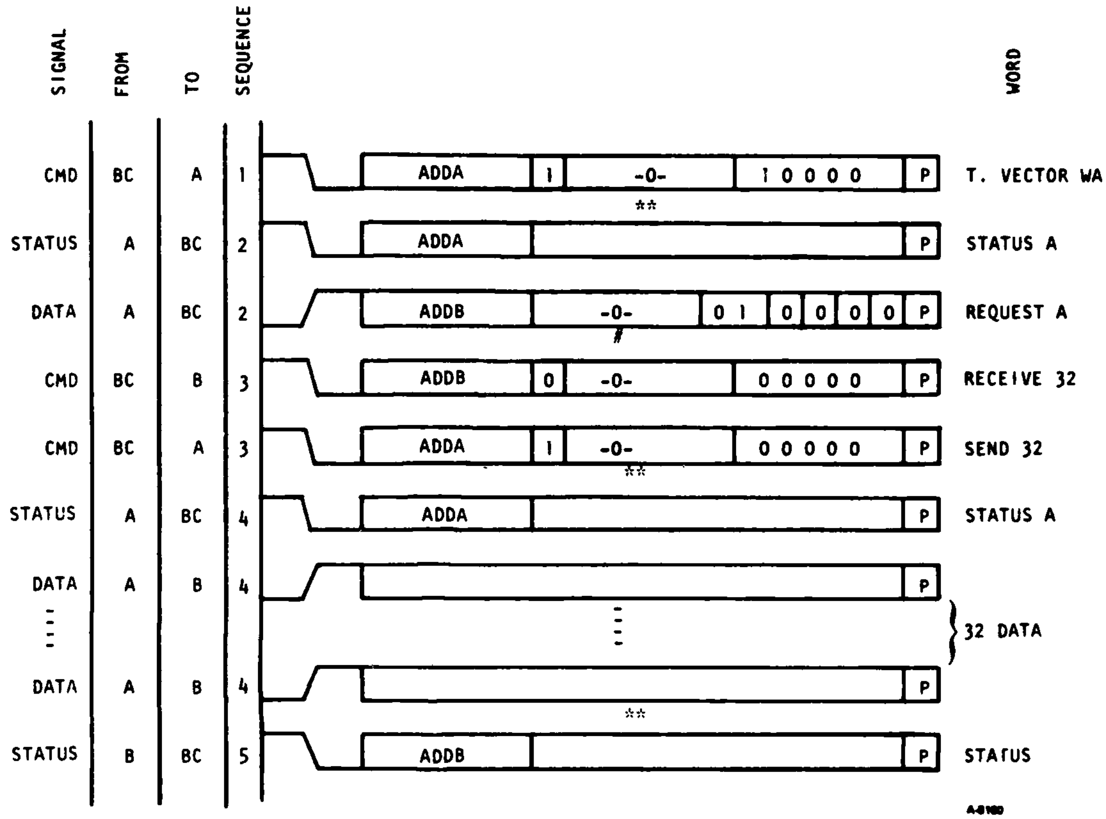


Figure 4-4. Transmission of Conversation From A to B

4.2.2.3 End of a Conversation

Reference is made here to Figure 4-5. When the crew member who initialized the conversation switches off the TO button (the microphone button is released and no message is pending) the bit END is set to one and is transmitted to the TO terminal via a BC transfer, which terminates the operation on the TO terminal (the light goes off).

4.2.3 Option: Conference Between Three Stations

The crew member A, who wants to establish a conference between A, X, and Y, successively pushes the following three buttons to the ON position:

C (conference), X, Y.

Terminal A, when receiving the C signal, waits for two station switches to be ON before setting the REQUEST WORD as follows:

		BOUT	E	Pr	C	R	
ADDX	ADDY				1	1	P

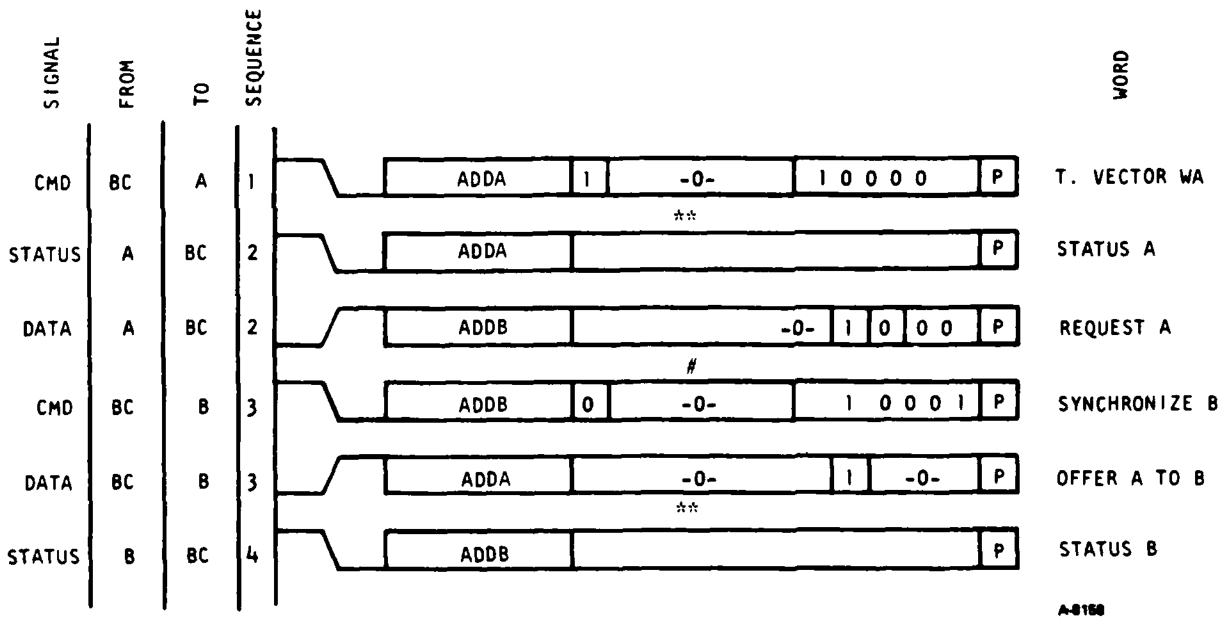


Figure 4-5. End of Conversation From A to B

The BC sends a synchronize command to X, offering A and Y, and a synchronize command to Y, offering A and X. If none of the terminals is busy, a synchronize command comes back to A. Three lights are lited on each panel: C, and the two other stations. These commands will set the broadcast mode in each terminal. The broadcast bit is set and no status is sent after receiving messages. In case one of the TO terminals is busy, the conversation is established between the two other ones and a blinking light appears on each panel. Figures 4-6 and 4-7 describe the establishment and the transmission.

4.2.4 Priority

If a crew member wants to use the priority channel, he sets the switch P on prior to set the switch of the TD station. The REQUEST WORD is then set as follows:

		BOUT	E	Pr	C	R	
o	ADDY			1		1	P

If the system is not equipped with the double-channel option for conference conversation, the exchange is granted if the terminal A priority level is higher than the priority level of the terminal already speaking to the TO station. Figure 4-8 shows the flow chart of the procedure.

If the system does have the conference option, the TO terminal utilizes the second channel if the first is busy. Otherwise the terminal speaking to this second channel is interrupted if its priority level is lower than the priority level of terminal A (Figure 4-8).

4.2.5 Broadcast

The broadcast mode is the option that allows one crew member to speak to all other crew members. Since the system described includes other terminals in addition to the audio terminals, the audio terminals will have specific sub-addresses, which are called channels 0 and 1 in this report. Thus, if a broadcast message is sent by one of the crew members, it is sent to the other crew members only, and not to the radio channels.

4.2.6 Tones

The tones will be implemented in the read only memory (ROM) of each terminal. The words corresponding to each tone will be directly transferred cyclicly in the buffer IN. The capacity needed for one tone is computed as follows:

(a) The rate of decodification of the voice is assumed to be 50,000 bits/sec bit time = 20 μsec

(b) The lowest frequency needed is 380 Hz. The cycle time is 2,631 μsec

(c) One cycle is defined by 2631/20 = 131.5 bits or 8.2 words of 16 bits.

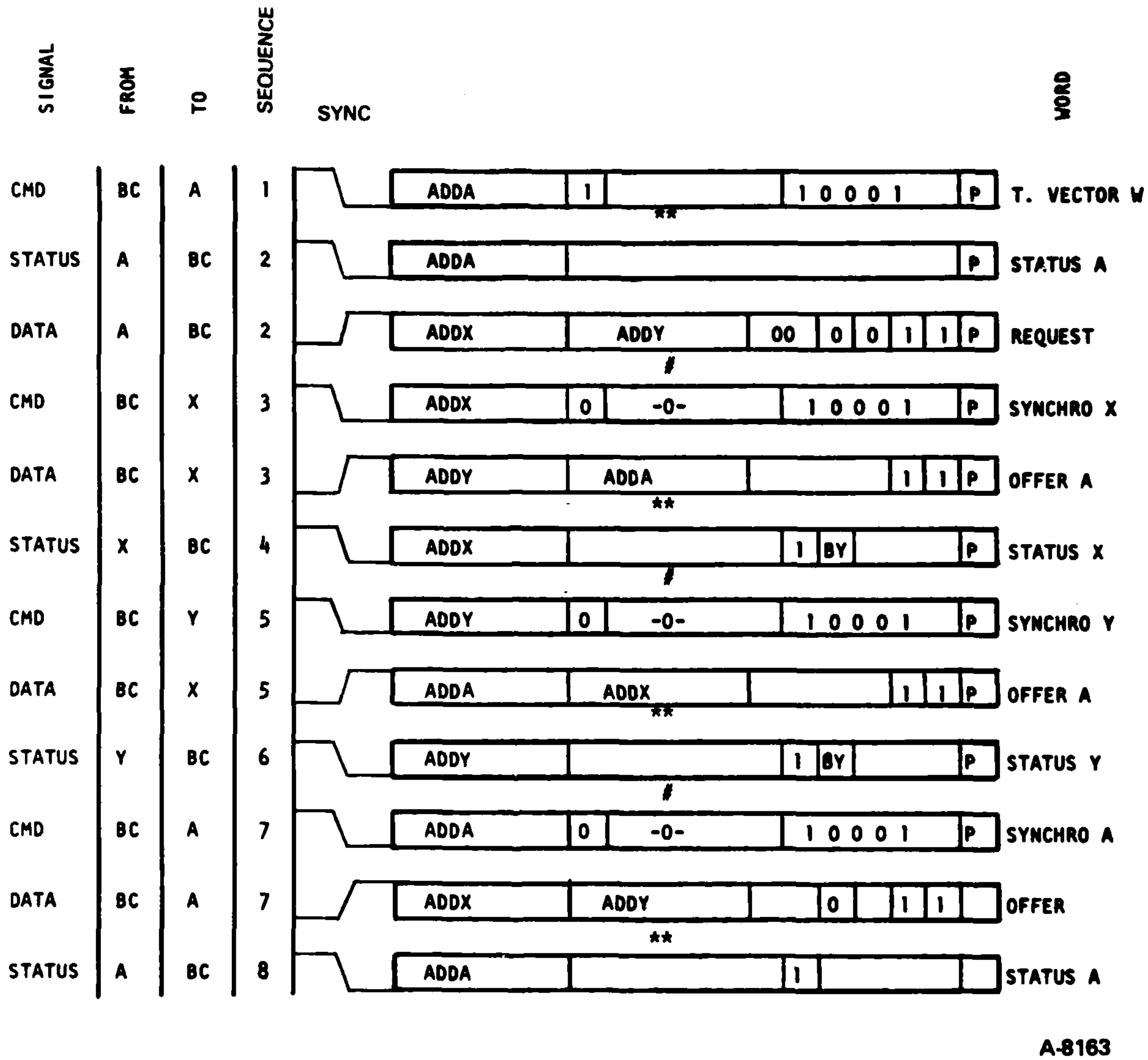
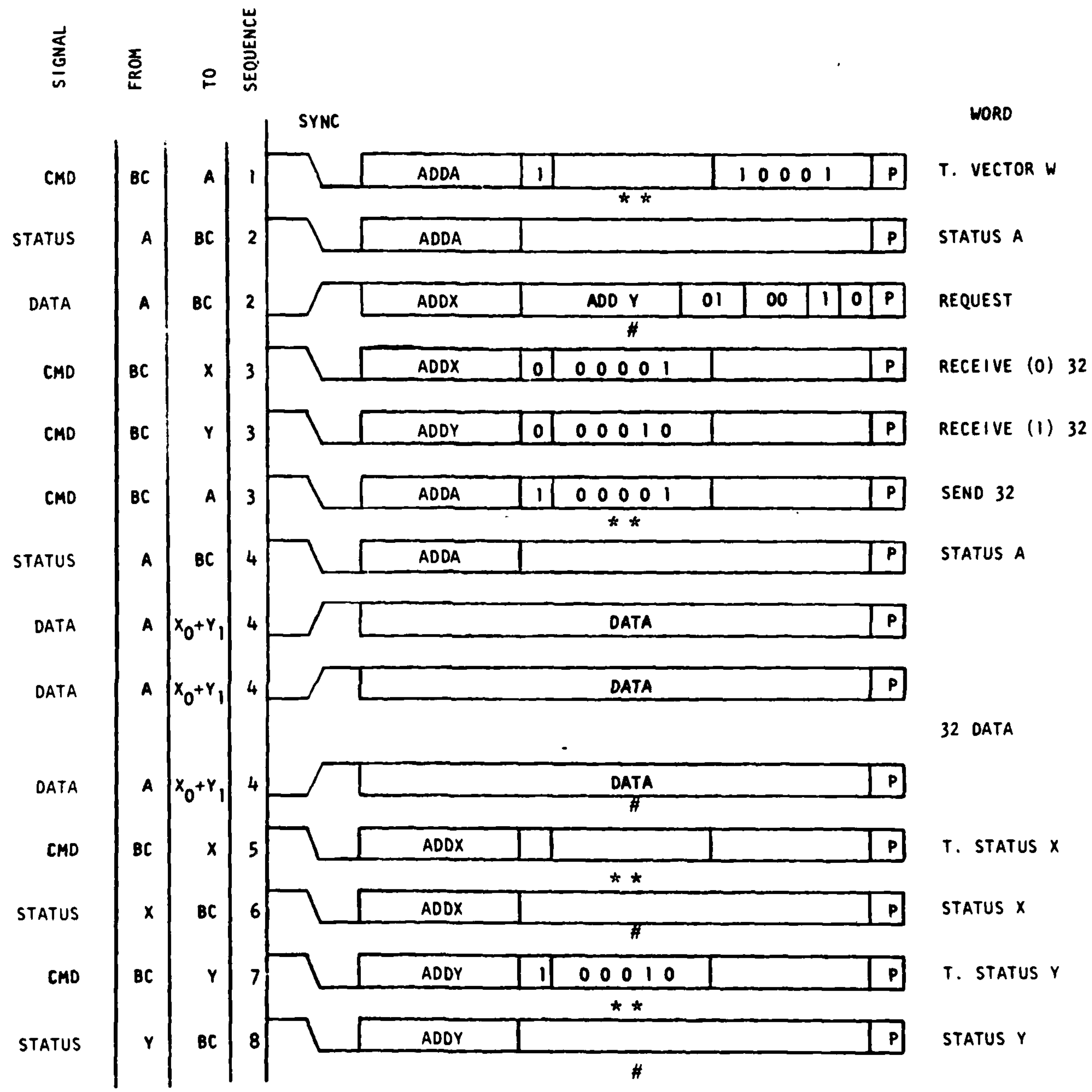


Figure 4-6. Establishment of Conference Between Terminals A, X, and Y



STATUS AT END OF EXCHANGE: TIMING = 43 x 20 + 4 x 12 + 4 x 10 = 34 µSEC EFF = 54 PERCENT
WITHOUT STATUS (5, 6, 7, 8) TIMING = 39 x 20 + 2 x 12 + 2 x 10 = 82 µSEC EFF = 62 PERCENT

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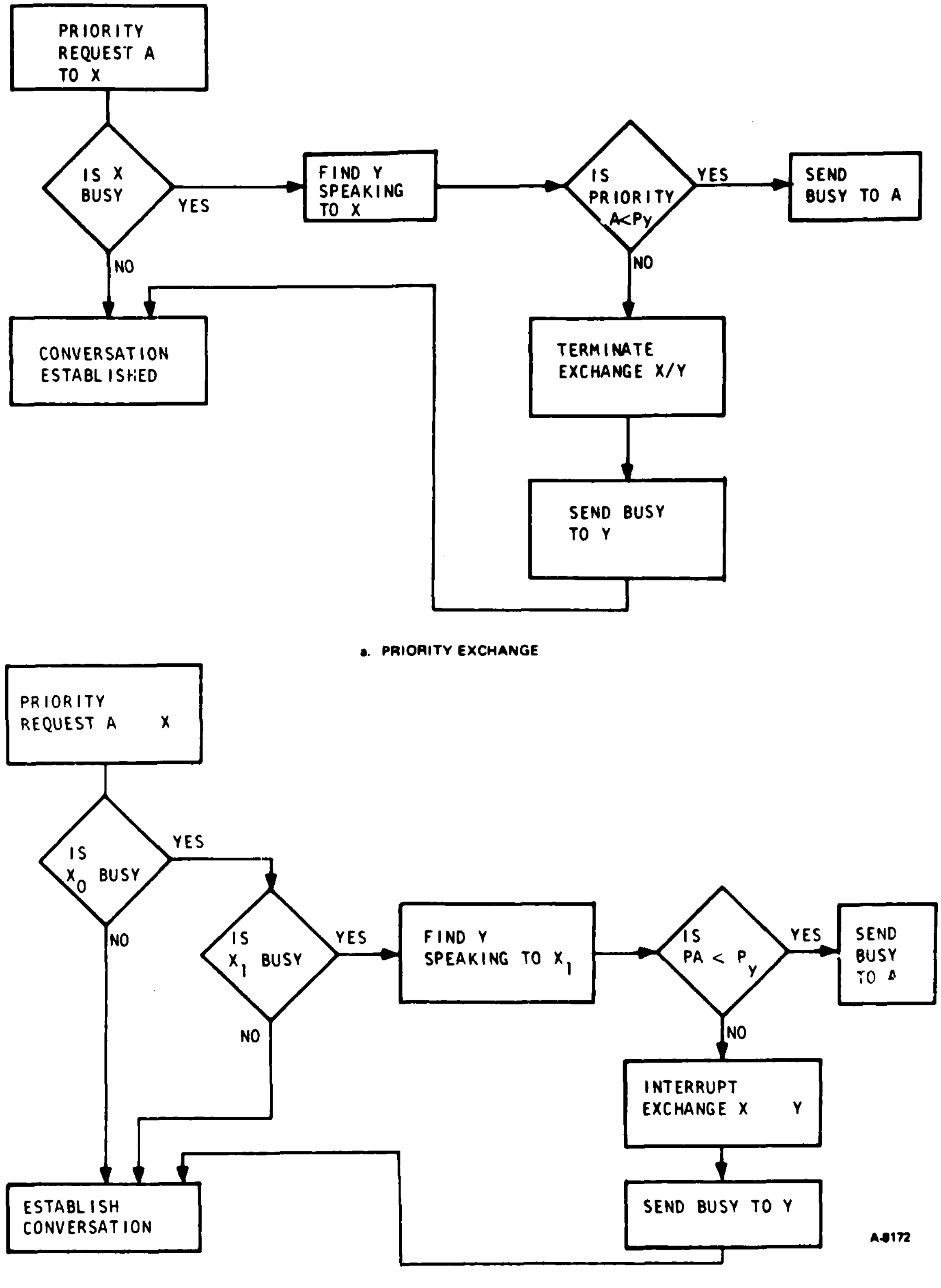
Figure 4-7. Transmission of Conversation From Terminal A to Terminals X and Y



b. PRIORITY EXCHANGE, CONFERENCE OPTION

Figure 4-8. Priority Exchange Flow Chart

(d) Ten words of 16 bits will be sufficient to define each tone, or 200 words for 20 tones.

The activation of the tones will be done by the following special offer word from the BC:

11111 11111	TONE #	P

(32 possibilities)

NOTES: 1. The code ADDX = ADDY = 11111 represents a special offer. The six remaining bits of the offer may be used as special commands like this tone activation.

2. When a tone command is received, the terminal automatically switches on 50,000 bits/sec (or to the frequency the words have been written for).

3. The tone command interrupts and replaces the voice decodification if a voice message is present. If the terminal is equipped with a second voice channel, the tone is automatically directed toward channel 2 and added to the voice.

4.2.7 Radio Communication

Communications with radio channels will be handled in the following way:

- Every radio channel is connected to a 1553B terminal almost identical to an audio terminal, except for the headset, which is replaced by the connection to the radio channel. The subaddresses will be different from the ones used for the audio terminals so that the broadcast mode inside the plane sends no messages to the radio channels.

- The tuning of the radio channels is done by specialized terminals, e.g., the CMS-80 terminals from Collins.

- A communication coming from a radio channel is automatically directed to one of the crew according to a program set at the initialization. A tone is activated in the designated terminal. The call can then be transferred to another station afterwards. (See Figures 3-8 through 3-10.)

5. AUDIO TERMINAL

The maximum number of terminals in a 1553B bus system is 31 (address 00000 to 11110, with address 11111 reserved for broadcast). Each terminal comprises the subassemblies listed in paras. 5.1 through 5.7.

5.1 BUS INTERFACE

The bus interface is able to send and receive status and data words to and from the 1553B bus. The integrated circuit utilized in the demonstration system delivered under the contract no. N62269-77-0236 (Harris HD-1553) is well adapted for this function.* This subassembly must be monitored by a clock that satisfies the 1553B specifications; i.e., 1 MHz +0.01 percent long-term, 0.001 percent short-term (1 sec). This condition is fulfilled by the crystal used in the demonstration system (a CR-60A/V, 12.0000 MHz crystal per MIL-C-3098). The system will have two bus systems; each terminal will be equipped with two interfaces.

5.2 TRANSFORMER ASSEMBLY

The bus interface is connected to the bus via a transformer assembly that isolates the terminal from the bus. The data bus wire pair is electrically floating per MIL-STD-1553B.

5.3 BUFFER ASSEMBLY

The buffer assembly consists of two buffers (IN and OUT). The management of these buffers is performed by the control assembly by pointers that keep track of how many words are to be sent. The function of these buffers is to allow the transformation of speed between the audio converter (25,000 or 50,000 bits/sec) and the bus (1,000,000 bits/sec). The concept of multiplexing the bus in time is realized by this subassembly, which stores the data from the bus in a short time and transmits it to the audio converter at a lower speed. If the terminal is equipped with a double audio converter to satisfy the requirement of dual reception, a supplementary BUFFER IN must be implemented. Figure 5-1 shows two BUFFER OUT subassemblies. The BUFFER OUT channel 1 is implemented for redundancy only, and may be activated by a switch if channel 0 is inoperative.

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*Note: Any equivalent LSI 1553 chip available from the industry may be utilized.

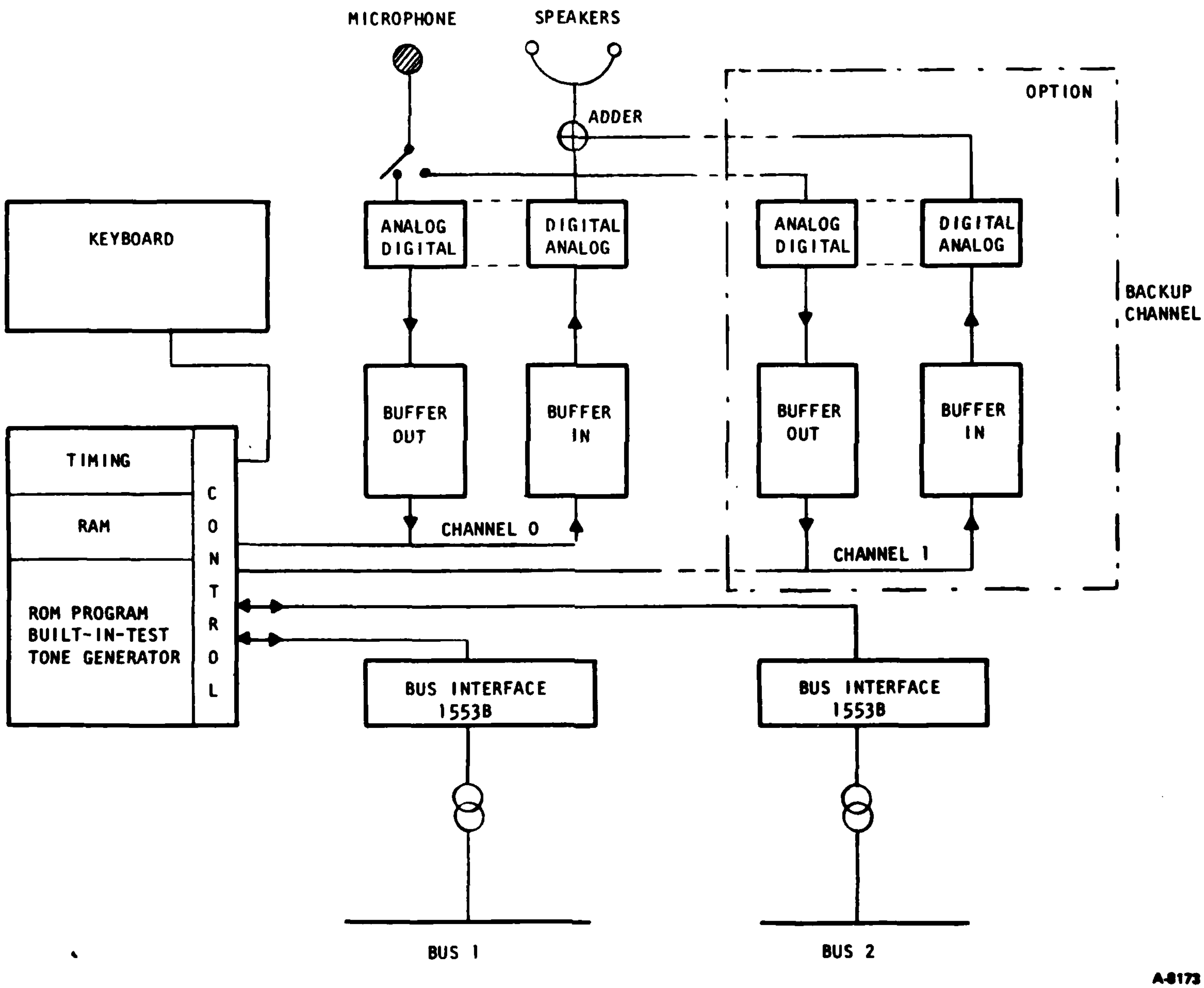


Figure 5-1. Audio Terminal

5.4 AUDIO CONVERTER

The audio converter transforms the voice signal from the microphone into digital data to be sent to the bus. This converter also transforms the digital data from the bus into an audible signal. Circuit MC3417, which was used in the demonstration system, utilizes the continuously variable slope delta (CVSD) principle for modulation and demodulation. The same circuit is used in this system because of its demonstrated qualities. However, any equivalent circuitry could be used.

As an option, a second audio converter as well as a BUFFER IN and a signal adder may be implemented in a terminal. This option offers:

(a) Possibility of adding one voice from the bus and one warning tone.

(b) Possibility of adding two voices from the bus for conference and priority calls.

(c) Redundancy that palliates a failure of an audio converter. If an additional BUFFER OUT is implemented, as shown in Figure 5-1, the microphone can be switched to the second channel.

5.5 HEADSET

Each AT is equipped with a standard output connected to the analog of the audio converter, typically at a 32-ohm impedance.

5.6 KEYBOARD DISPLAY

5.6.1 Keyboard Description

The panel of the audio terminal shown in Figure 5-2 is equipped with:

One switch per audio terminal for selection of the TO terminal

One light per audio terminal (lighted for an established conversation, blinking when busy)

One switch for priority (P)

One switch for broadcast (B)

One switch for conversation (C) between three terminals (option)

One switch (R) to communicate with the radio

One rotative switch to select the radio channel

One switch (PP) for program priority to change the priorities of the system

One switch (T) for test to ask for a BIT test procedure

One balance button for conference (for the two-channel option only)

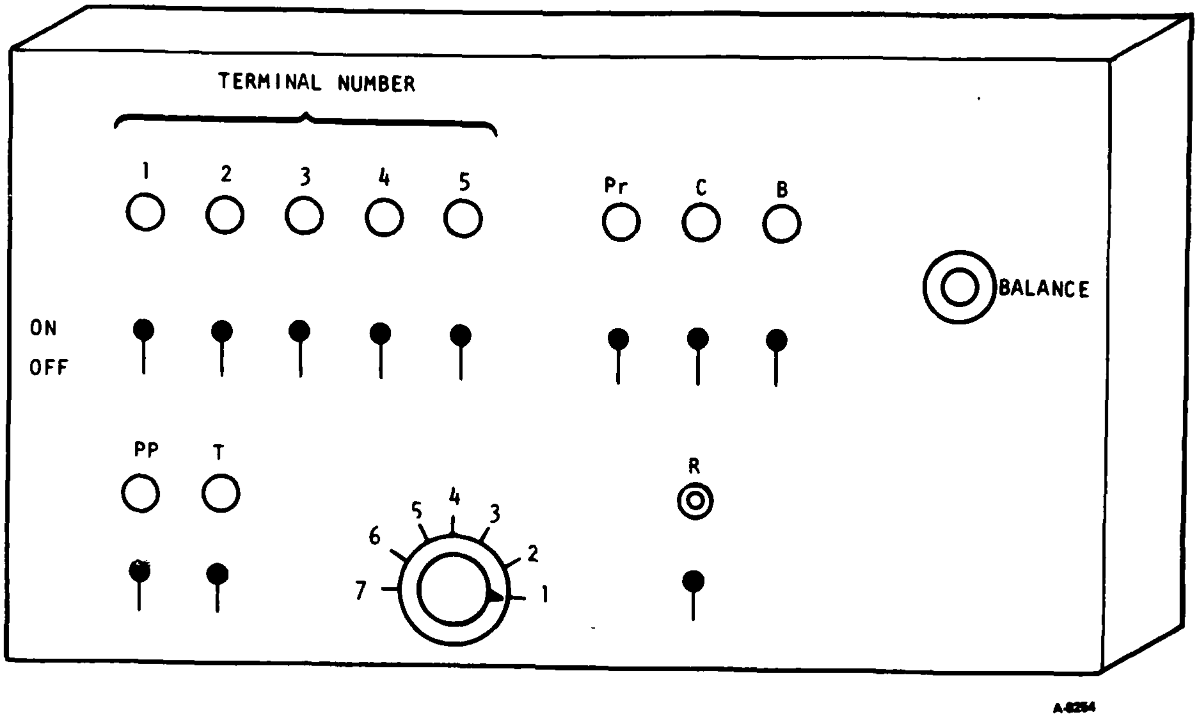


Figure 5-2. Audio Terminal Keyboard

5.6.2 Keyboard Operation

A crew member activates the button corresponding to the station he wants to talk to. If the TO station is busy, the corresponding light starts blinking on the two panels and a tone is generated at the TO station. If the TO station is not busy, the conversation is established in less than 10 msec (for a system with 10 terminals), the two lights are lighted and each person can talk to the other by activating the microphone switch.

The broadcast mode is obtained in activating the B switch. An option requiring a more developed software system allows the broadcast mode to be activated by the microphone switch alone.

A PRIORITY button allows a crew member to interrupt a conversation when his priority level is high enough. The table of priority is established at the generation of the system and generally gives the highest level to the pilot. The pilot may modify the priority levels in activating the switch PP and then setting the station switches on (the first one will have the highest level). The same PP button will be used to allocate the receivers of the radio communications (see radio channels). Figure 4-8 of Section 4 shows the flow chart for a call using the Pr button.

As an option, a conference call can be established by setting the C switch ON and then setting the two stations to be included in the conference. This option includes a balance button.

When a call comes through a radio channel, the crew member who receives the tone switches the selector to the corresponding channel number (channels 1 through 7, as shown in Figure 5-1).

The priorities can be changed by the station that has the highest priority by using the switch priority program (PP) in the following way:

(a) PP switch ON

(b) Depress 2, 1, 3, 4, 5 to set the station 2 at a higher priority than stations 1, 3, 4, 5

(c) Switch PP OFF

(d) Priority of radio communication

In the conference option, a conversation can be established between three persons in which one crew member can listen to the other two. This mode can be set from one station by depressing the corresponding number and the C push-button. This option includes a balance button.

5.7 CONTROL

5.7.1 Definition

The control unit is connected to all subassemblies of the terminal and is a computer unit, with a CPU, ROM containing the microprogram, RAM containing the information, and I/O channels.

One of the main constraints of the terminal is to achieve a response time less than 12 μsec. A cycle time of 1 sec for the control is a reasonable performance for the control (ROM, controller and logic), so that 12 microprogram instructions can be performed in less than 12 μsec. The functions to be performed by the terminal are the following (see Figure 5-3).

5.7.2 Functions of Audio Multiplex Terminal

5.7.2.1 Receipt of Words From Bus

A terminal can receive any word sent by another terminal or the bus controller via the bus. It first recognizes the SYNC signal (command or data) contained in the first three bit times of any word; it then stores the 17 remaining bits and checks the parity bit.

If the word is a command word, the terminal compares the terminal address field to its own address. It then executes the command contained in the rest of the word if a positive comparison occurs.

Data words received after a valid receive command word are stored in the IN buffer. Data words received after a command containing another terminal's address, or after a nonvalid command, are ignored.

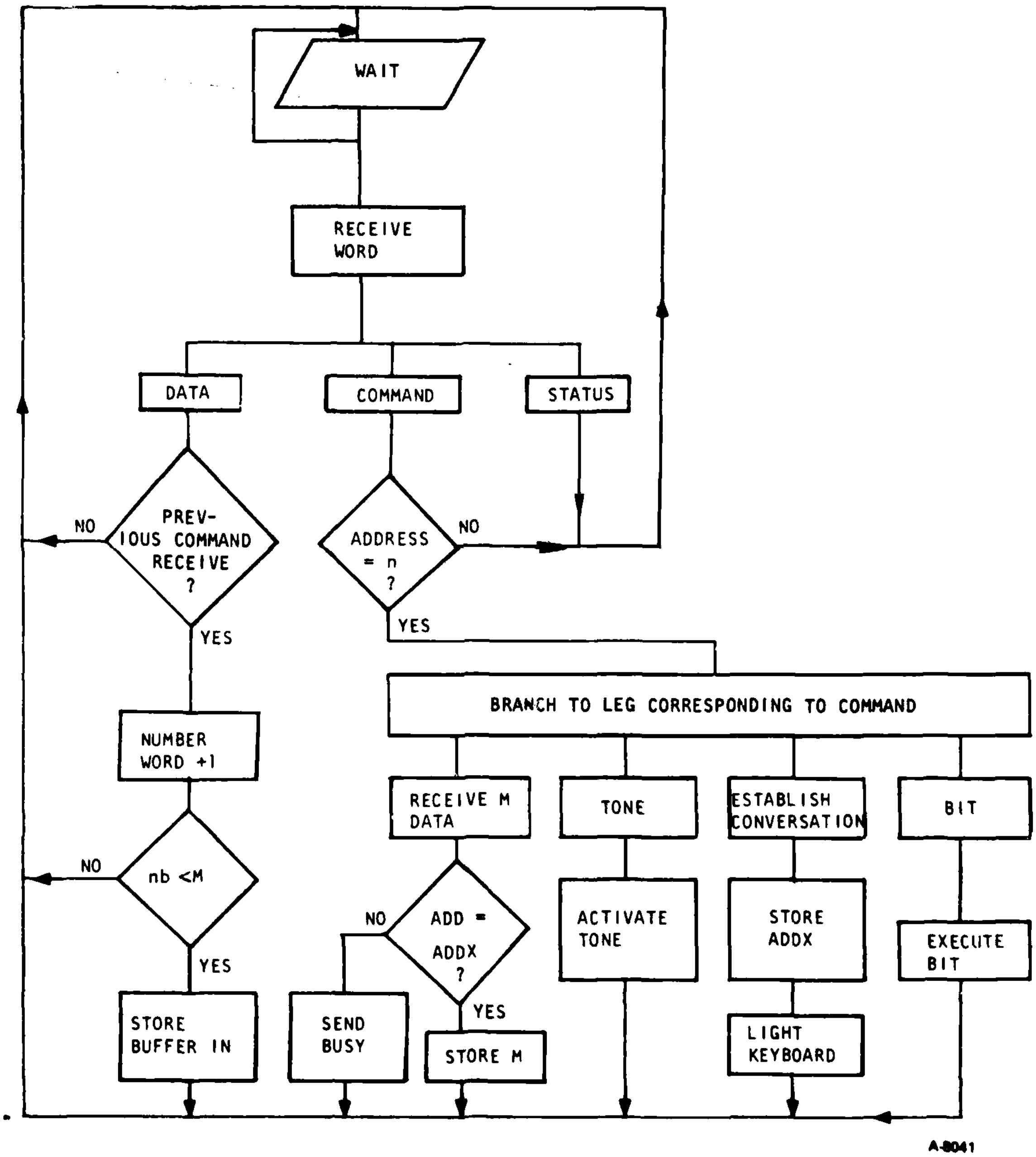


Figure 5-3. Flow Chart for Audio Terminal Reception

5.7.2.2 Transmission to Bus

The terminal sends STATUS words that set all bits to the proper value. The terminal sends REQUEST WORDS to the bus. This REQUEST word contains information to establish a conversation. When communication is established, the REQUEST word contains the information needed for the transfers.

Transmission functions of the audio multiplex terminal include:

- Receipt of data from the audio converter and storage of this data in the BUFFER OUT.
- Transfer of data from the BUFFER IN into the audio converter.
- Generation of warning tones.
- Test in real time of each operation (parity, SYNC, validity, timings, etc.)
- Error procedures like:

    Restart an exchange

    Switching subassembly (internal redundancy) or bus (external redundancy)

- Management of the keyboard display by reading all pushbuttons and actuating the lights.
- Realization of built-in test (BIT) and transmission of the results to the BC upon request.
- Modification of the speed of audio converter speed (e.g., 50,000, 25,000, or 16,000 bits/sec). This is an option for large systems.
- Management of the traffic to and from a subsystem connected directly to the audio multiplex terminal.

5.8 CONNECTION TO CMS-80 SYSTEM

The audio terminals can be connected to a bus controlled by a controller like the CMS-80 if the software accommodates the protocol described in this report, and especially if direct RT-to-RT transfers are incorporated.

A CMS-80 type of terminal may be used to replace the keyboard of the terminal, but this feature should be an option because the number of audio terminals is generally greater than the number of CCD's. The protocol would have to be modified so that a conversation is initialized by a CCD and then transferred to an audio terminal.

Communications with radio channels will be handled in the following way:

(a) Every radio channel is connected to a 1553B terminal almost identical to an audio terminal, except for the headset, which is replaced by the connection to the radio channel. The subaddresses will be different from the ones used for the audio terminals so that the broadcast made inside the plane is not sending any message to the radio channels.

(b) The tuning of the radio channels is done by specialized integrated control/status terminals such as the CMS-80 system from Collins.

(c) A communication coming from a radio channel is automatically directed to one of the crew member, according to a program set at the initialization. A tone is activated in the designated terminal. The call can then be transferred to another station.

6. BUS CONTROLLER

6.1 DESCRIPTION

A bus controller is defined as the terminal that initiates the information transfers on the bus.

6.2 FUNCTIONS

The bus controller performs the following functions:

- Initiates conversations between terminals (between two or three terminals, broadcast option, and radio)
- Monitors all exchanges and records errors
- Initiates error procedures like:

  Reinitiating the faulty exchanges a certain number of times

  Deciding to switch to the other bus

  Deciding to switch to the other bus controller
- Initiates internal checking procedures like BIT
- Sends initialization data to the terminals after a power on sequence
- Manages the priority levels

6.3 SUBASSEMBLIES OF BUS CONTROLLER (BC)

The BC comprises the following subassemblies:

(a) A bus interface identical to the one defined for the terminal.

(b) A transformer assembly the same as the one defined for the terminal.

(c) A control, which is the main part of the bus controller; it includes a processor, a ROM, and a RAM. The programs and working areas of the memory are shown in Figures 6-1 and 6-2.

The cycle times of the control and RAM are to be under 1 μsec.

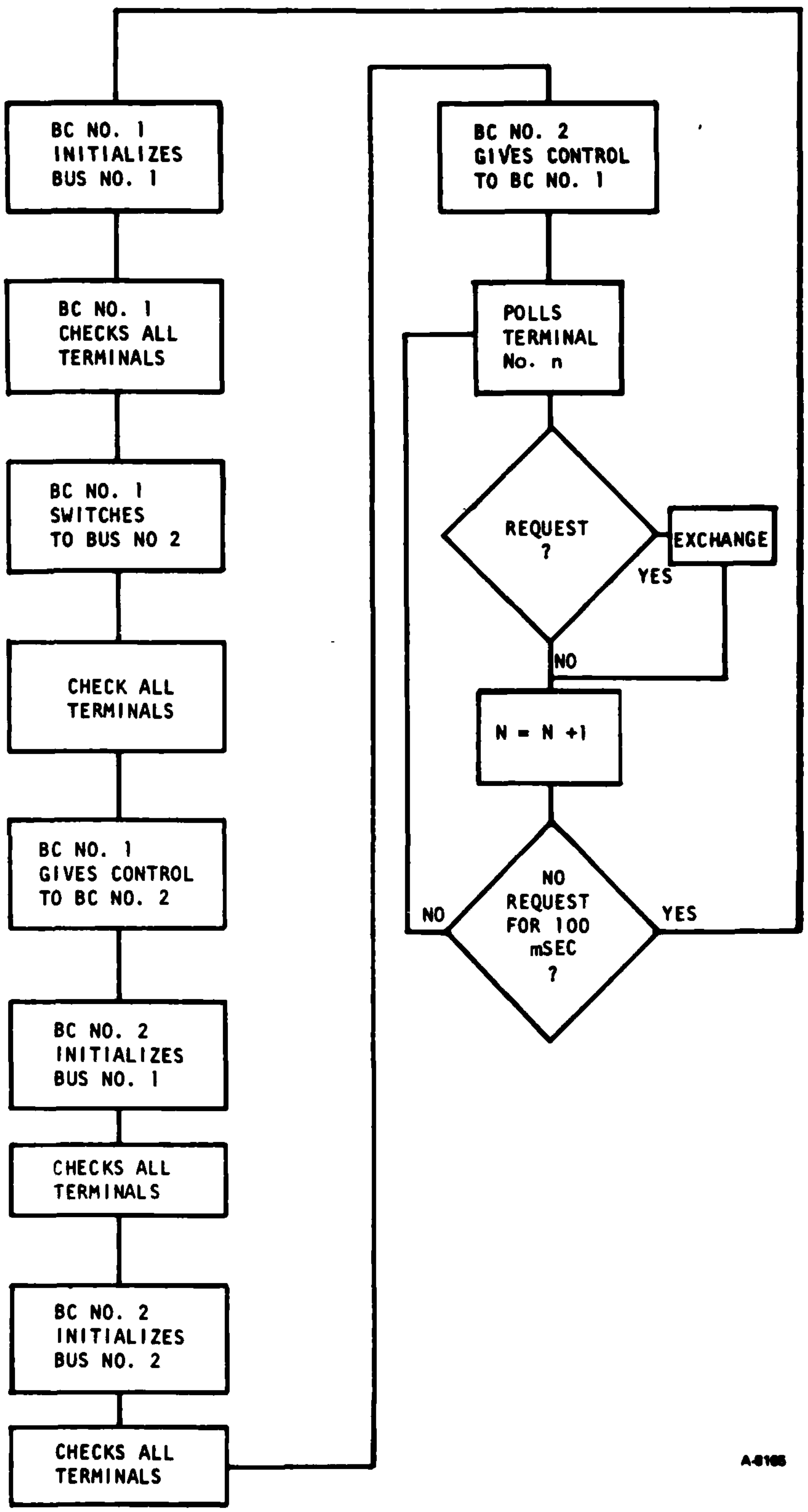


Figure 6-1. Bus Controller General Flow Chart

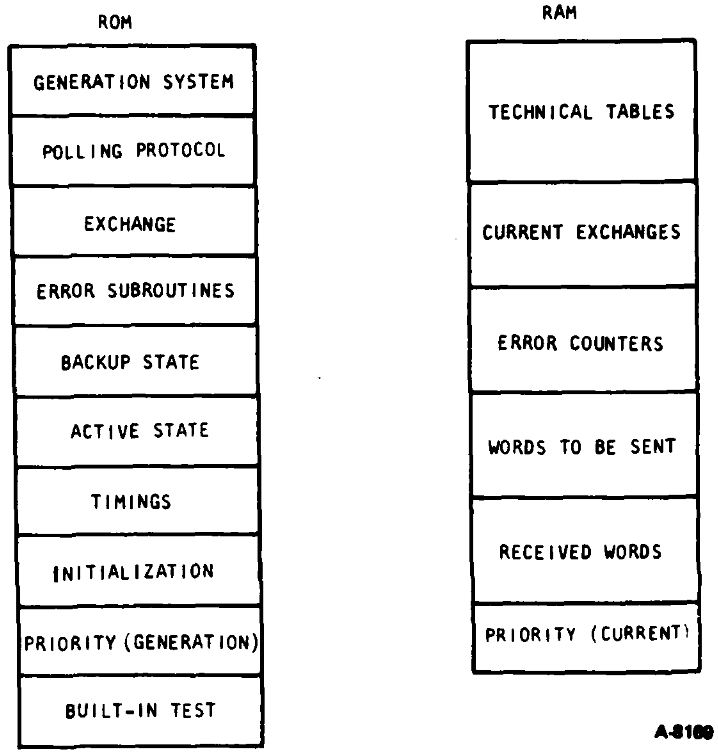


Figure 6-2. Memory Content

6.4 BUS CONTROLLER OPERATION

The controller can be in two states--active and backup.

6.4.1 Active State

At the initialization of the system, the configuration of the system is stored into the BC in terms of (1) addresses, subaddresses, and priority levels of each terminal, and (2) subaddresses of the warning tones inside each terminal.

During the initialization sequence that follows POWER ON, the BC ensures that the system corresponds to this configuration. The BC then polls the terminals, activates all the functions, tests both buses, and asks for the BIT to be performed. The active BC gives temporary control to the backup BC, which performs the same initialization sequence before giving control back to the active BC. Then the BC continuously polls the terminals and follows the protocol described in this report.

When a period of time without communication is observed (e.g., 100 msec) or when an operator activates the switch test, the BC performs an initialization sequence.

6.4.2 Backup State

In the backup state, the BC sits in an idle loop and controls the timings of the messages from the bus. It changes its state to active in case of a BC time out (the other BC does not answer) or in case it receives a command DYNAMIC BUS CONTROL.

In its backup state, the BC does not send any command to the bus; it is considered as a terminal by the active BC. At the power ON sequence, one of the BC's will switch to the backup state, and the other will switch to the active state. This feature is hardwired by jumpers.

Although the level of computation of the controller is low and part of the control is left to other parts of the system (e.g., parity is controlled by the bus interface), the architecture of the control must be very flexibile in order to accommodate the different protocols of MIL-STD-1553B.

The number of repetitive tasks to be executed dictates the selection of a microprogram controller able to perform subroutines. Figure 6-3 shows the principle of control with:

(a) A microprogram controller that provides sequential access, conditional branching, subroutines, loops, and branching to an address given by an external component (mapping PROM)

(b) A mapping ROM, containing the addresses of the sequence to be executed

(c) An ALU to perform the following typical operations: analysis of bits and fields, comparison, and incrementation/decrementation

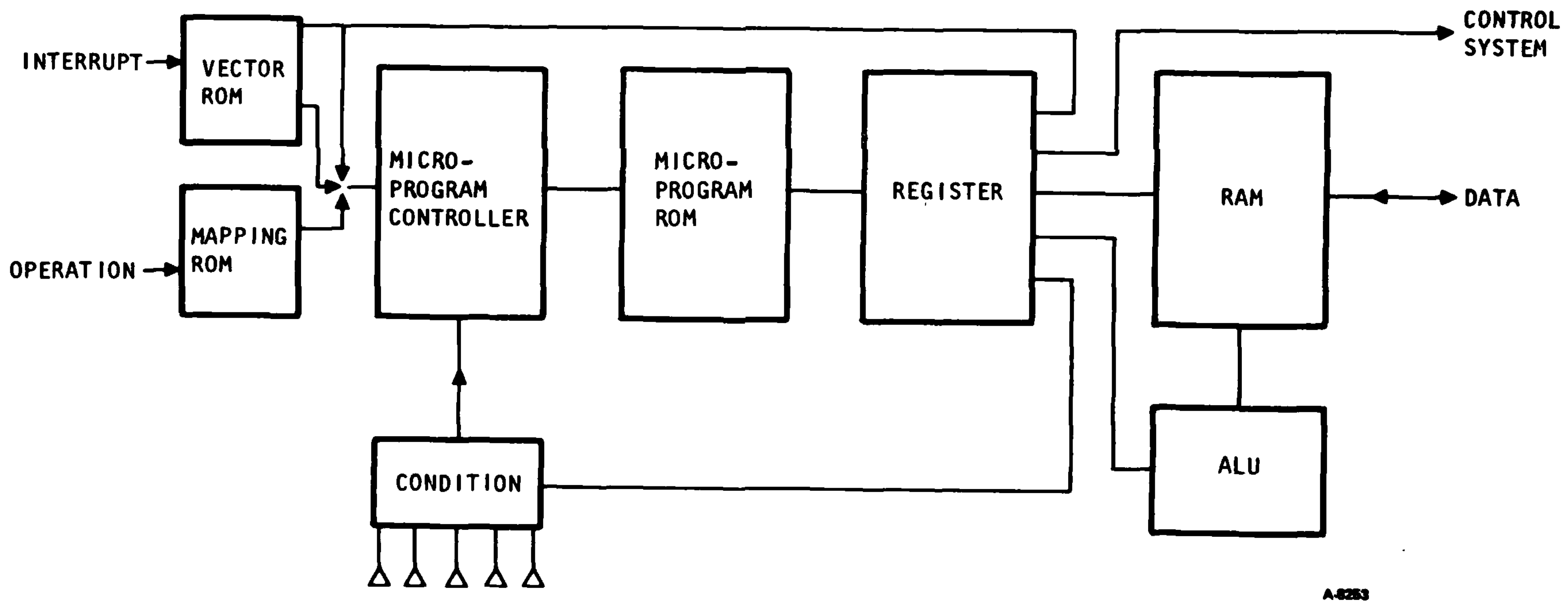


Figure 6-3. Control Subassembly

6.5 CONNECTION TO COCKPIT MANAGEMENT SYSTEM (CMS)

The CMS-80 system developed by Collins (or an equivalent CMS) can be utilized to control the audio system. The CMS-80 controller accommodates the protocol presented in this report with a modification of the software. The terminals (CCD's) can be utilized to show the faults of the audio multiplexer with messages like:

STATION #X = interface A fails

STATION #Y = interface B fails

STATION #Z = completely down

STATION #A = BIT fails

The CMS-80 display can be used to show the following activities of the audio terminal:

- Messages replacing the lights on the keyboard

  BUSY: Means that the person the operator wants to talk to is already emitting or receiving

  BROADCAST: Signifies that the broadcast mode is set and that the operator is now emitting in broadcast mode

  CONFIDENTIAL: Indicates that the operator is currently emitting in a confidential mode

  CONVERSATION: For a conversation between three persons

  PRIORITY: Used when priority is demanded by the operator

  RADIO CHANNEL

- FAULTS: Indicates that faults are occurring on the system, such as

  STATION #X channel 0 fails

  STATION #Y channel l fails

  STATION #Z: interface A fails

The display may indicate the solutions the system has taken to be able to function when possible, such as

STATION #D: BUS INTERFACE #B FAILS

SYSTEM ON BUS #A

A page could be reserved to indicate the traffic on the audio multiplexer, for instance:

02-10 / 05-04 / 08-17

21-BR

Such an indication could mean that station 02 is talking to stations 10, 05 to 04, and 08 to 17, and that station 21 is broadcasting to all other stations.

The CMS-80 terminal may be used to check the system by commands like:

Switch bus

Perform test sequence on terminal

7. WEIGHT AND POWER

This section describes the physical characteristics of the audio terminal and bus controller. The technology utilized in the design of the audio terminal and the bus controller will be highly integrated, and will incorporate low-power circuits. Because the cycle time for the processor and the memories is about 1 sec, CMOS technology can be utilized. The present estimate is based on existing devices.

7.1 AUDIO TERMINAL

An audio terminal (AT) comprises the components shown in Table 7-1 and Figure 7-1.

A total of 500 mw power is required for the five 100-mw LED's on the front panel. Total power required is 4.675 w. The total surface of electronic components is 16.320 sq in. If implemented on a two-sided printed wiring board (PWB) the total surface is to be multiplied by 2--a practice that has been verified by experience with similar hardware. Thus, the surface of the two-sided PWB is 32.64 sq in., which can be divided into two boards of 4.4 by 3.7 in.

A switching power supply is recommended to reduce size and weight. A power supply able to deliver 5 w should be able to be contained in 16 cu in. Both power supplies would be contained in 5 by 4.4 by 1.6 in., as can be seen in Figure 7-1, which shows a typical audio terminal. The terminal defined by this figure has the following characteristics:

Dimensions:	5 by 5 by 3 in.
Power Supply:	5 w, redundant
Weight:	2.25 lb.

7.2 BUS CONTROLLER

Components of the bus controller (BC) are defined in Table 7-2 and Figure 7-2.

The BC has about the same requirements as the audio terminal. The size of the memory is larger, but the BC is not equipped with an interface to the headset and does not require a front panel.

Thus, the configuration of the BC will be very similar to that of the AT. It will have the same chassis (but with a blank front panel), the same double power supply, and the same PWB format. This should simplify the development and production, and lower the costs.

Characteristics of a bus controller are:

Dimensions:	5 by 5 by 3 in.
Power supply:	5 w, redundant
Weight:	2.1 lb.

TABLE 7-1

POWER CONSUMPTION AND SIZE OF
AUDIO TERMINAL COMPONENTS

	Number	Power per IC, mw	Power, mw	Surface per IC, sq in.	Component Surface, sq in.
ROM: Two IC's of 8K x 8 bits (8K words x 16 bits)	2	200	400	1.3 x 0.625	1.625
RAM: Two IC's of 2K x 8 bits (2K words x 16 bits)	2	200	400	1.3 x 0.625	1.625
Microsequencer: One IC	1	100	100	2 x 0.625	1.250
ALU: Four IC's (CMOS)	4	20	80	2 x 0.625	1.250
CARRY: One IC (CMOS)	1	20	20	0.87 x 0.325	0.283
CVSD circuit (example: MC3417)	2	50	100	0.87 x 0.325	0.566
Encoder/decoder (example: (example: HD 15531)	2	50	100	2 x 0.625	9.500
Bus receiver (part of emitter)	2	525	1,050	--	--
Bus emitter (one active at a time)	2	1,125	1,125	0.87 x 0.325	0.566
Transformer	2	--	--	0.63 x 0.63	0.400
Buffers, latches, logic (low power)	10	20	200	0.87 x 0.325	2.83
Panel interface	2	40	80	1.3 x 0.625	1.625
Resistors, diodes, capacitors, transistors	(40)	3	120	0.20 x 0.10	0.800
Protection, clock, etc.	--	--	400	--	1.000
Total	30		4,175		16.320

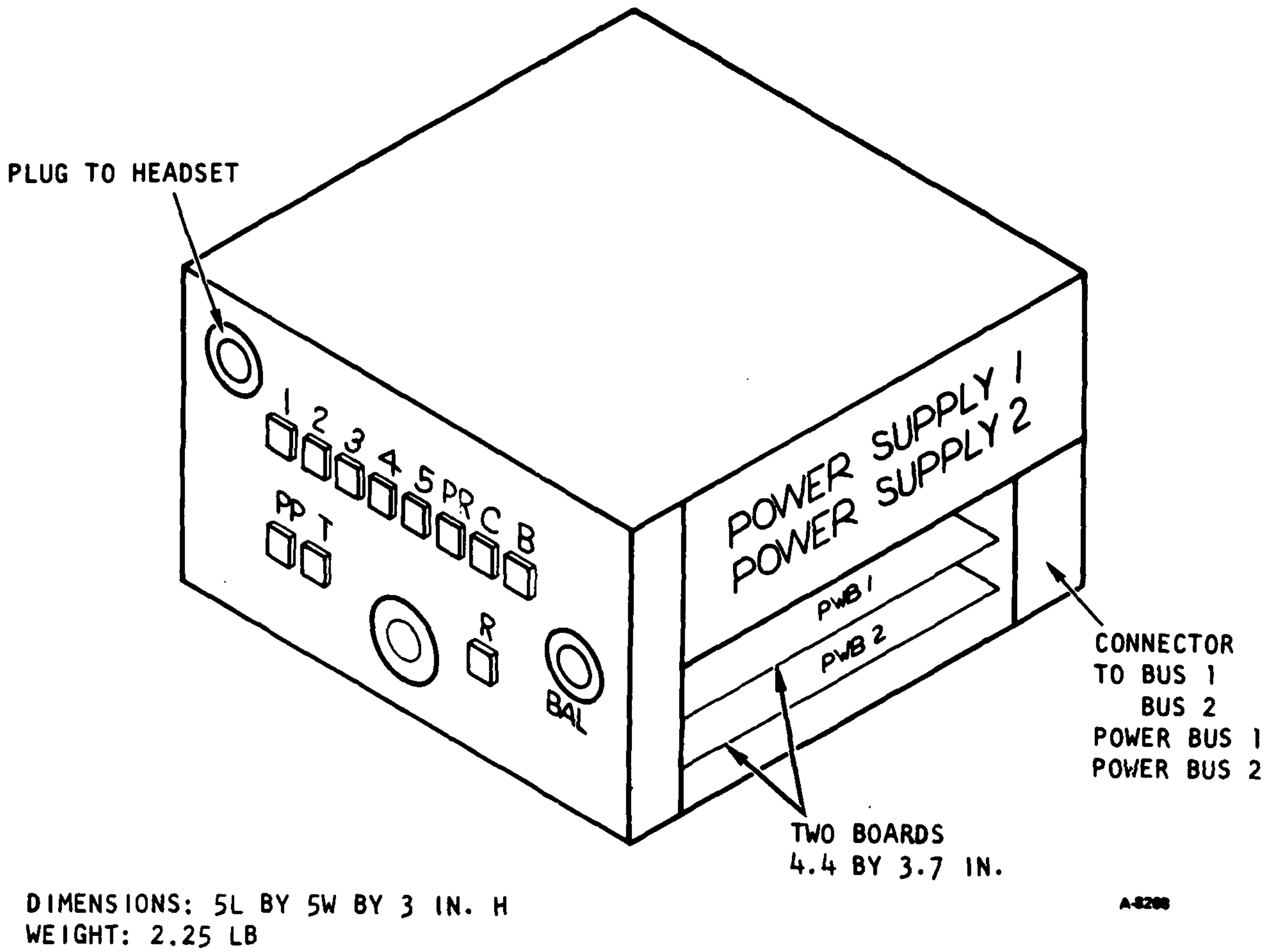
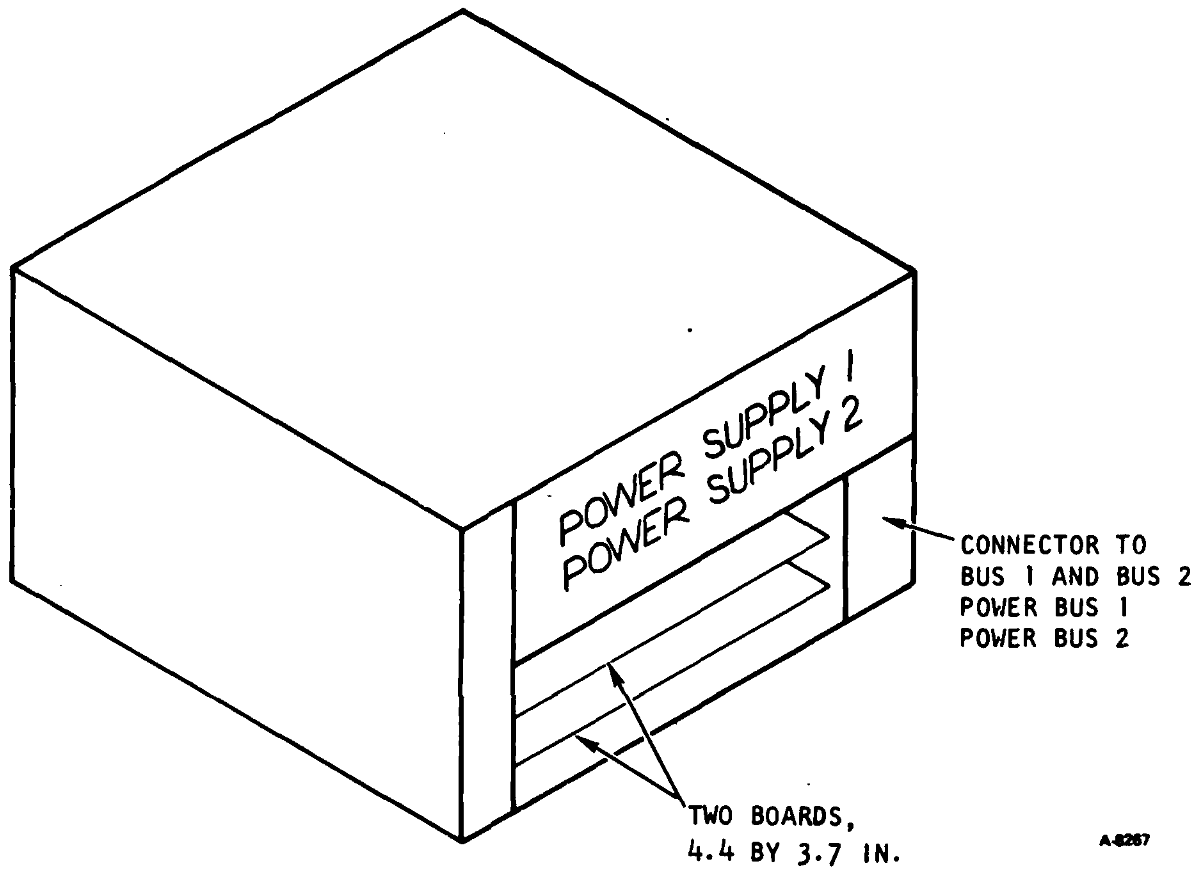


Figure 7-1. Audioterminal

TABLE 7-2

SIZE AND POWER CONSUMPTION
OF BC COMPONENTS

	Number	Power per IC, mw	Power, mw	Surface per IC, sq in.	Component Surface sq in.
ROM: Four IC's (8K x 8 bits) = 16K x 16 bits	4	200	800	1.3 x 0.625	3.25
RAM: Four IC's (2K x 8 bits) = 4K x 16 bits	4	200	800	1.3 x 0.625	3.25
Microsequencer	1	100	100	2 x 0.625	1.250
ALU: Four IC's (4 bits) CMOS	4	20	80	2 x 0.625	1.250
CARRY: CMOS	1	20	20	0.87 x 0.325	0.283
Encoder/decoder (example: HD 15531)	2	50	100	2 x 0.625	2.500
Bus receiver (included in emitter)	2	525	1,050	---	---
Bus emitter (one active at a time)	2	1125	1,125	0.87 x 0.325	0.566
Transformer	2	--	--	0.63 x 0.63	0.400
Buffers, latches, logic (low power)	5	20	100	0.87 x 0.325	1.41
Resistors, diodes, capacitors, transistors	(40)	3	120	0.20 x 0.10	0.800
Protection, clock, etc.	--	--	400	---	1.000
Total	27	--	4,625	---	15.959



DIMENSIONS: 5 L BY 5 W BY 3 IN. H

WEIGHT: 2.1 LB

Figure 7-2. Bus Controller

APPENDIX A

SUMMARY OF MIL-STD-1553B

Specification MIL-STD-1553B almost entirely defines the process of transmission along the bus, the word formats, and the general specification of the hardware. A summary of this specification is as follows:

(a) The transmission uses words of 20 bit times in a Manchester II biphase level data code at a rate of 1 megabit per second. Three different formats (command, status, data) are used, with specified gaps between messages (4 to 12 μsec).

(b) The system includes bus controllers (BC's) and remote terminals (RT's). The transmission can be established between two RT's or one RT and one BC. The utilization of the bus is multiplexed in time to satisfy the application.

The main features of the MIL-STD-1553B are summarized as follows:

- Serial transmission on the bus, asynchronous, half-duplex
- Pulse-coded modulation
- Manchester II biphase level
- Transmission bit rate: 1 MHz $\pm$10 (1 sec), $\pm$100 (long-term)
- Word size: 16 bits + $P_{(odd)}$ + 2 x 1.5 = 20 bits (20 μsec)
- Word formats: COMAND, DATA, STATUS
- Maximum number of terminals 32-1 = 31 (11111 = broadcast)
- Subaddresses = 32 - 2 = 30, (0 and 31 are reserved)
- Maximum number of words per message = 32 (640 μsec)
- Mode code: functions to be performed by a terminal
- Broadcast option (address = 11111)
- Bus controller defined as necessary (implicit). It is dynamic, and may be integrated in an RT.
- Self test
- Multibus option
- Intermessage gap = 4 μsec

- Response time from 4 to 12 μsec = T
- Time out = 14 μsec
- Control of time out + time transmission time (800 μsec/40 words)
- Monitor--records information for off-line application or backup BC
- Transmission line: jacketed, twisted, shielded pair
- Capacitance 30 pF/ft
- Characteristic impedance: $70 \leq Z_o \leq 85$ at 1 MHz
- Attenuation: 1.5 dB/100 ft
- Stub length: 20 ft maximum
- Cable termination: both ends in Zo
- Coupling transformer required
- Output waveform: Rise/fall times: 100 to 300 nsec
- Distortion: 300 mv peak-to-peak and line-to-line on bus
- Transmitter output noise: 14 mv RMS line-to-line
- Output voltage on bus: 18 to 27 v
- Signal shape: square to sine wave
- Response range: 1.2 to 20 v. No response: 0.0 to 0.28 v
- Common mode rejection: ±10.0 v peak; dc = 1 to 2.0 MHz
- Input impedance: 1000 ohm from 75 KHz to 1 MHz

APPENDIX B

GENERAL-PURPOSE AUDIO MULTIPLEXED INTERCOM SYSTEM (ICS) OCTOBER 11, 1978

ABSTRACT

The development of a demonstration model multiplexing system for audio intercom communications has been sponsored by the Naval Air Development Center (NADC). The model system codes audio information using a continuous, variable-slope, delta-squared modulation technique. Audiofrequency response is limited for voice recognition and intelligiblity, minimizing the data rate requirement. Relations between audio sampling rate, intelligibility, bus loading, and capacity for additional terminals are discussed.

Transmission is in MIL-STD-1553 formats. A form of dynamic bus allocation is used to control the intermittent requirements for data transmission. The system can share a bus with other avionic systems using 1553 protocols. Bus availability requirements for a shared system are discussed, relating availability to apparent audio delay.

Advantages of the digital system are covered, including ability to share communications channels with other data, suitability for scrambling or encryption, and incorporation or alarms or warnings.

PROBLEM STATEMENT

The problem statement is associated with the development, design, and fabrication of a five-station, general-purpose, audio multiplex intercom system (ICS) based on a 1553 time divsion multiplexing technique for the purposes of experimentation and laboaratory evaluation by NADC. The objective of this program is to provide an audio multiplex system for general-purpose use within Navy airborne platforms. The system must be structured so that it can be contracted or expanded to accommmodate a minimum of two audiostations to a maximum of twenty. The approach to the audiomultiplexer is to be one of total system integration and not as a separate piecemeal system. The multiplexing of audio signals must be accomplished using transmission over a MIL-STD-1553 Command/ Response System or over the polling structure defined by MIL-G-85013(AS).

SYSTEM CONFIGURATION

The basis audio multiplexer shown in Figure 1 consists of a number of stations (from 2 to 20), avionic tone simulator, and a system bus controller. The system uses a common bus to multiplex data and commands between stations and between the bus controller and stations. Communications protocol on the bus is per MIL-G-85013(AS) polling-contention mode, while data transfers between elements of the audiomultiplexer are performed per MIL-STD-1553A waveform and timing requirements. This combination is equivalent to MIL-STD-1553B dynamic bus allocation.

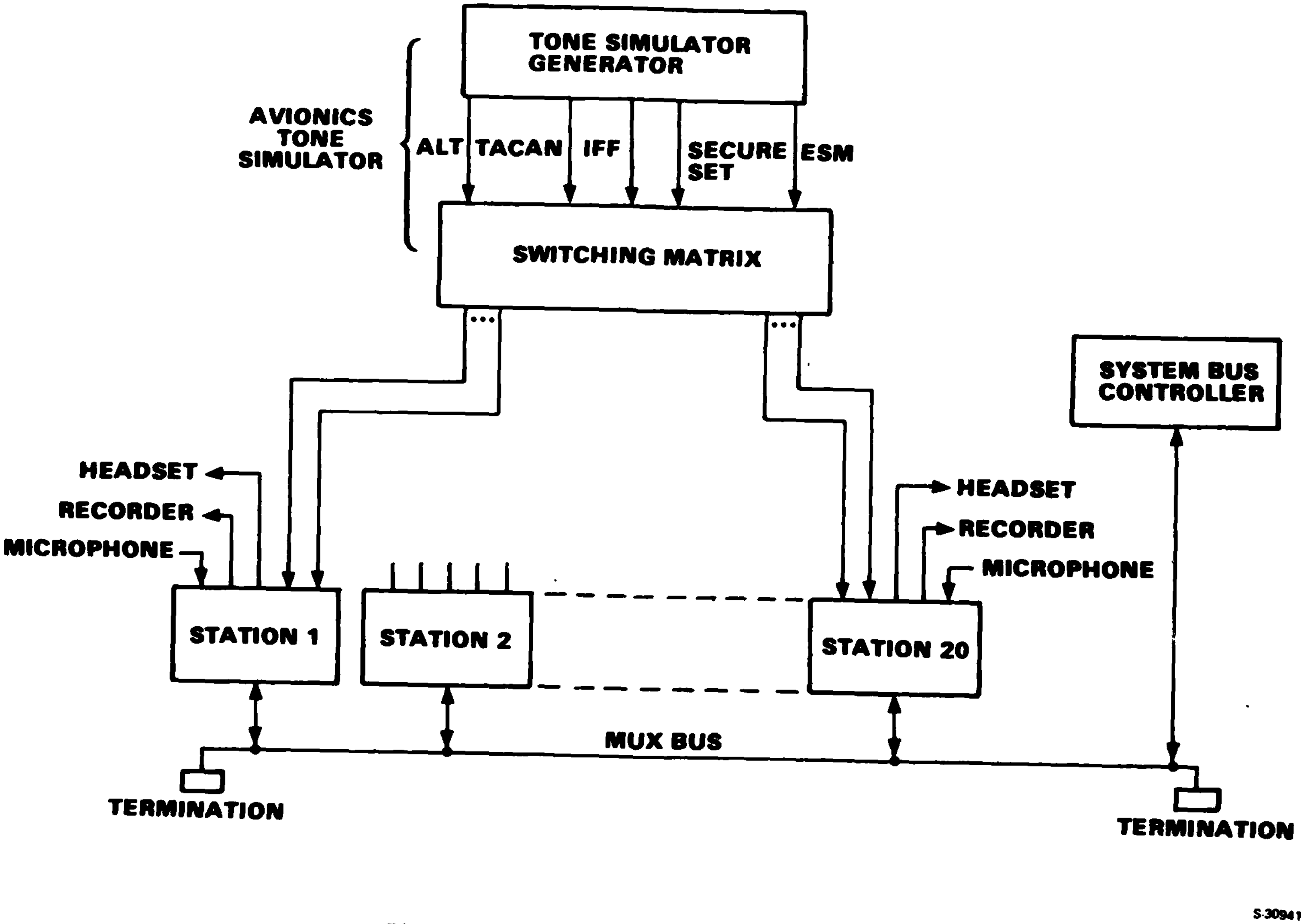


Figure 1. Audio Multiplexer Block Diagram

The avionic tone simulator generates tones associated with particular avionic equipment. These tones are steered by the switching matrix to various stations to simulate several warning tone sources. Each station receives inputs from the avionic tone simulator switching matirx, microphone, and the intercom system multiplex bus, and provides outputs to the multiplex bus, headset, and recorder.

SYSTEM FEATURES

The AiResearch general-purpose audio multiplex system is designed for five stations, and is expandable to twenty or more. The communication method and transmission format adopts the physical operating and general message characteristics associated with MIL-STD-1553A (or B). All message protocol and associated control data and status words are transmitted over the same 1553 bus.

Multiple communications modes highlight yet another feature of the ICS. This system is designed to provide the following operational modes:

(1) "Party line" operation—one person talks and all others listen.

(2) "Separate" converstion--multiple two-way communications. Bus capacity up to approximately 10 conversations.

(3) Combination of modes (1) and (2).

The ability to mix both party line and separate conversations represents a naturai byproduct associated with the successful development of the NADC audio multiplex program.

In addition to providing for conversations, the ICS also handles aural warnings from various avionic sources. These warnings might consist of those associated with IFF, sonar, RAWS, altitude, landing gear, and others. Generally, these warnings have unique audio characteristics that allow segregation of the specific warning taking place. For example, an oscillator of 1050 ± 50 pulses per second produces an IFF warning tone in contrast to that of summing 512-Hz, 614-Hz, and 768-Hz oscillators that provide still another tone peculiar to altitude warnings.

Any warning tone or combination of tones may be switched to any station. These warning tones are then encoded to a specified bit position of the first data word of the message transmitted. This method provides the presence of this warning condition to other recieiving terminals via the multiplex bus. The receiving terminal then reads the corresponding bit position of this data word and triggers an oscillator. This produces a warning tone that can be audibly mixed with an ongoing conversation, permitting both the warning tone and voice communication to be heard. The demonstration system handles five warnings with capacity designed for sixteen, requiring no change to message or data word formats. Since multiple warnings may be introduced to a terminal at one time, indicators are provided at each terminal for verification of each warning condition.

AUDIO PROCESSING

In past reviews, multiplexing voice over a 1553-type data bus has appeared difficult and impractical. This stemmed mainly from the continuous nature of the analog voice signal as compared to the quantized 1553 digital system's 20-microsecond words. Sytems have been considered where the transmission of a single voice signal, in a digital form, would load the system and not allow time for the transmission of any other signals.

A different system concept and modern integrated circuits have made audio multiplexing practical for future systems.

A first consideration in digital audio multiplexing is how much data, i.e., bits per second, is required to be transmitted. The AiResearch-developed entertainment multiplexing system of a few years ago used 300,000 bits per second. This was, in fact, a hi-fi system. Some of the new companding (non-linear PCM) integrated circuits for telephones use 9 kHz samplers of 8 bits, 64,000 bits per second. These systems should produce extremely high voice quality. Recently produced integrated circuits for voice use rates of 16,000 bits/sec and greater. These units use versions of delta modulation (one bit A/D) called continuous, variable-slope delta modulator and accommodate a wide dynamic range of signals. Aural warning systems have been built by AiReseach for NASA using delta modualtion at an even lower data rate (10,000 bits/sec). Voice quality was just adequate for the intended word recognition requirement, but not for voice recognition.

The 1553 data bus, of course, has a capacity of 1,000,000 bits/sec. The NADC specification called for a system expandable to 20 stations. If all 20 are allowed to talk at once (not necessarily a requirement), then, not considering bus operating overhead, the maximum sample rate would be 50,000 bits/sec. Synchronization and parity bits associated with 1553 transmission use 20 percent of the bus capacity, lowering the maximum psossible rate to 40,000 bits/sec. Other overhead associated with the bus operation reduces the bit rate even further. The audio multiplexer uses a 25 kHz sample rate to meet the 20-station requirement with reasonable quality. Voice recognition at this rate is very good. Future systems may use lower frequencies (like 16 kHz) with newer integrated circuits.

At a 25-kHz sample rate, a bit is generated every 40 microseconds. Since this is two 1553 word times, it is impractical to handle the bits individually over the bus. However, if bits are stored in the transmitting station until an appropriate quantitiy is available and then transmitted in groups, a convenient system may be devised.

Consider the following analogy: there are two large buckets, as shown in Figure 2. One bucket has water running into it at a fixed rate, and the second bucket, with an outflow spigot, has water running out at the same fixed rate as the water to the input bucket. You stand by the buckets with a dipper. When the water level in the first bucket reaches a certain level, you move a dipper of water from the first bucket to the second. You repeat this process at such a rate that the first bucket never overflows and that there is always enough water in that bucket for your dipper when you dip. If the

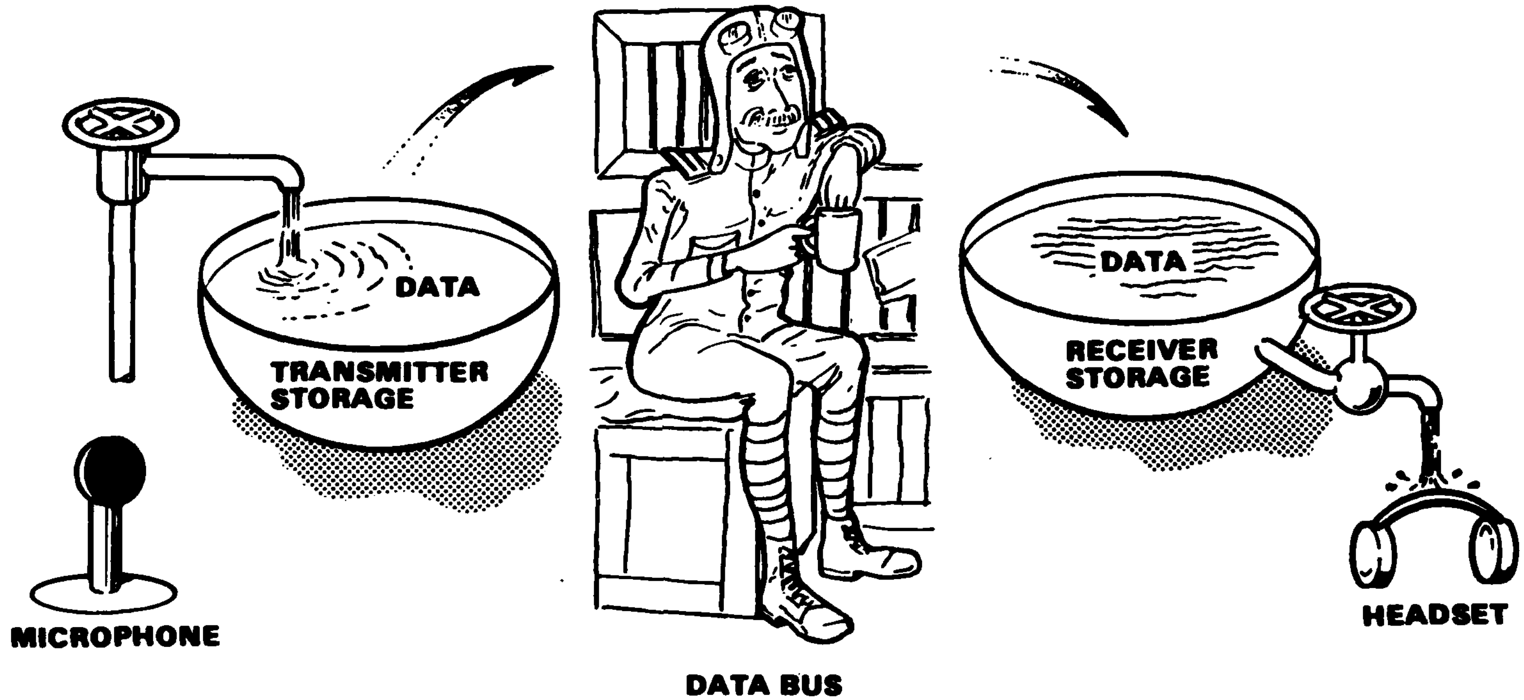


Figure 2. Bucket-by-Bucket Analogy

input to the first bucket and the output from the second are exactly equal, then the output from the second are exactly equal, then the output from the second will be continuous and uninterrupted. Note that over a long period of time the rate of water moved by the dipper is (and must be) the same as the input/output on the bus. Another operational analogy can be garnered from this model: the output of a particular segment of water does not occur directly after its input; there is a built-in delay.

ICS COMMUNICATION

The AiResearch audio multiplex system operates much as the model described. The transmitter converts voice to bits and stores 512 before transmission can start. Approximately every 10.24 milliseconds, 256 voice bits (16 data words) are transmitted. In the receiving station(s), 512 bits are received (two transmissions) and stored before the analog output is started. The delay through the system from voice in to voice out is approximately 40 to 50 milliseconds, below the threshold of perceptibility to the user.

Upon power turn-on, the bus controller offers the multiplex bus to the first audio multiplex station and sets an internal timer within the bus controller. The bus controller then tests the bus status to determine if the bus is busy. When the bus enters the idle state, the bus controller can offer the bus to the next audio multiplex station. The bus controller continues this activity until all stations have been offered the bus. The controller then waits until the sample time interval (10 milliseconds) has been reached. The bus controller then resets the counter and again offers the bus to audio-multiplex system stations. When the bus is offered to a station, it will not respond if it has no message to transmit, and the bus controller will reacquire the bus. If the station has a message, it transmits a command (receive) to the first station, as defined by the address switches. This latter station (receiving) will transmit a status word back to the first (transmitting) station. A bit in the status word will indicate if the receiving station is busy. If the transmitting station is communicating to other stations, it will, after receiving the first receiving station's status word, transmit a command (receive) to the next station and receive a status. This continues until all stations to receive have been notified and have responded; the transmitting station then transmits 17 data words that will be received by all receiving stations at the same time.

All stations receive a bus offer each 10.24 millisecond frame. Communicatons can occur simultaneously betwen two stations. Audio multiplex communications protocol and message word formats are presented in Figures 3 and 4, respectively.

STATION DESIGN

One of the demonstration stations is shown in Figure 5. A station consists of input and output amplifiers, variable-slope, delta-squared decoder and coder, input and output memories, a bus transmitter and bus receiver, switch address logic, warning circuits, and microprogram controller. A block diagram of the station is presented in Figure 6.

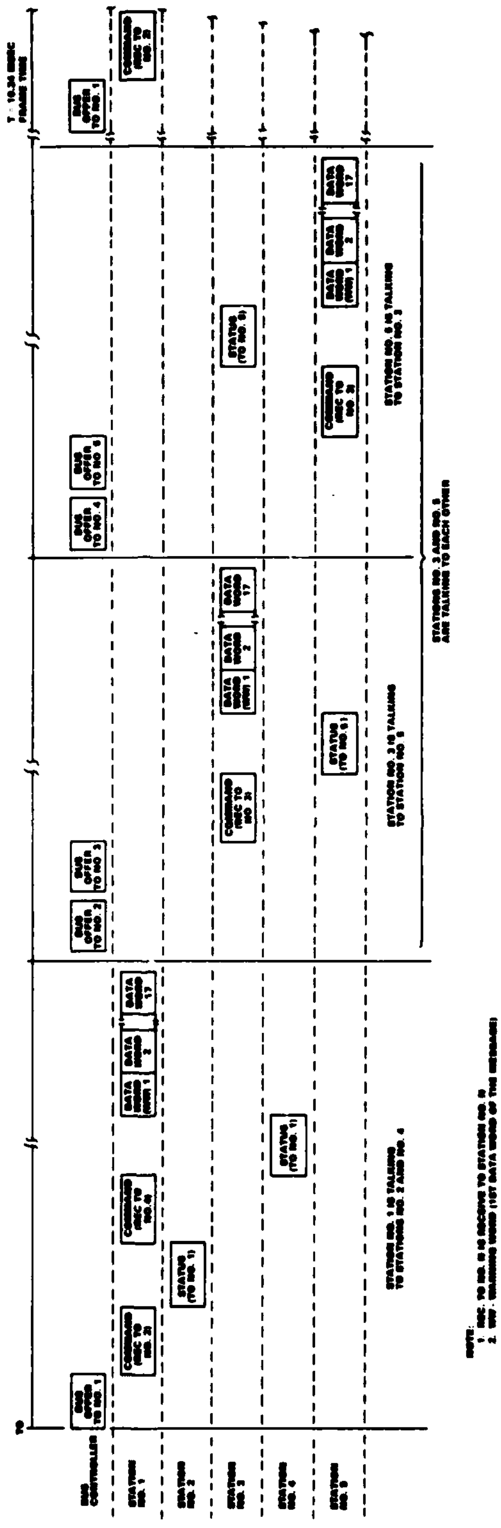


Figure 3. ICS Communications Protocol

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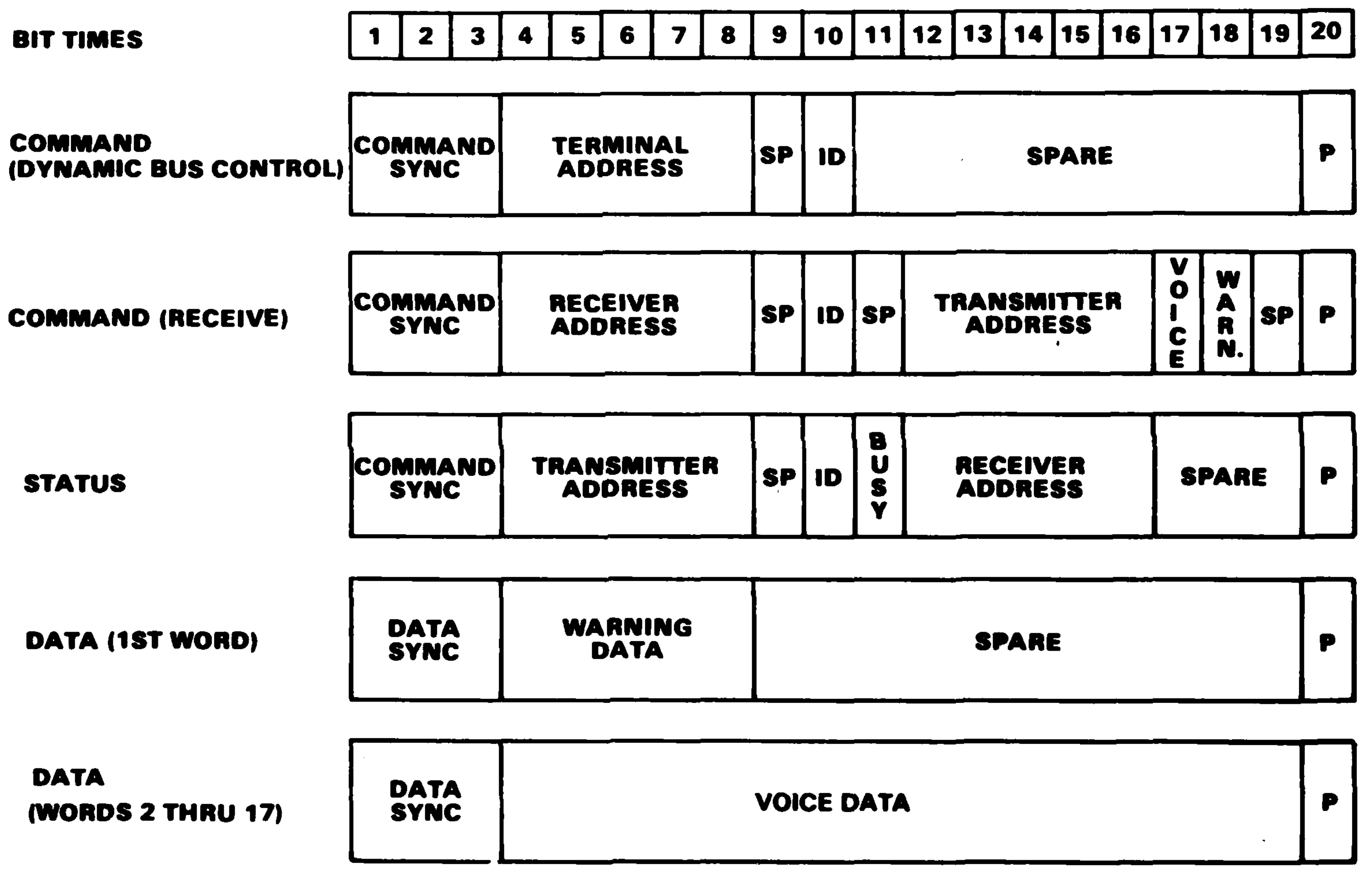

Figure 4. Audio Multiplex ICS Word Formats

80668-20

Figure 5. Typical Station

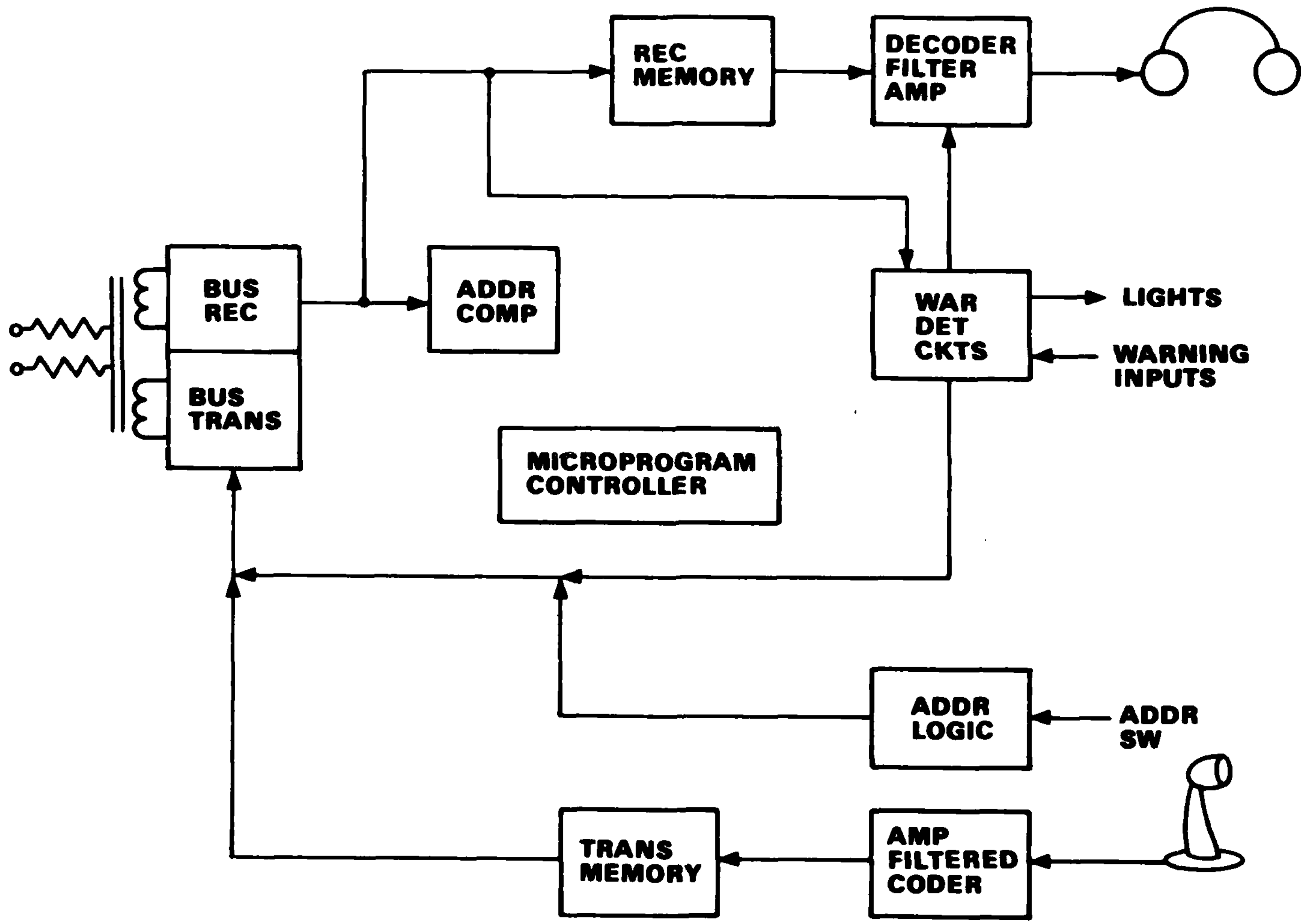

Figure 6. Audio Multiplex Station Block Diagram

The input amplifier scales and filters the incoming audio signals. The delta squared coder converts the analog signal into a series of digital pulses. These pulses are stored temporarily in the transmitter memory. When sufficient data are stored, they will, under microprogram control, be output to the bus transmitter.

The bus transmitter outputs the data to the bus, again under microprogram control, when the appropriate control work has been received from the bus controller.

The bus receiver receives data from the bus and outputs the data to address comparison logic, the receiver memeory, and warning circuits. Under microprogram control, the receiver determines the type of data from the address comparison units, and bus receiver control bits (command sync, data sync, etc.); then, when appropriate, it directs the data to the receiver memory.

In the receiver memory the data are stored temporarily until required by the decoder. The decoder converts the digital data back into an analog signal, which is then output to the headset.

The warning circuits are multifunctional since they:

(1) Accept warning inputs and sum them with the audio output of the station.

(2) Set a warning discrete that is transmitted to all other stations.

(3) Accept warning discretes from other stations and start the appropriate warning oscillator.

(4) Sum the local oscillator signal into the station output.

(5) Turn on appropriate warning lights.

The switch address logic generates the appropriate station address from the toggle switch inputs. This information is transmitted under microprogram control.

Two principal areas associated with audiomultiplex design required particular attention during design and development phases of the system. The first was optimizing encoding/decoding for the highest degree of audio fidelity versus the number of bits per data word required to produce the audio tone. The second was the packing and unpacking of audio data, which required a tradeoff analysis between message size and fidelity versus the number of stations in the system. A significant factor in this decision is the optimization of memory sizes within the station compared with transmission time and bus loading associated with the number of stations.

FUTURE TRENDS

Many applications exist for future versions of the basic audiomultiplexer described in this paper. The ICS could assume a wide variety of configurations

for both airborne and ground-based systems. A possible configuration of the ICS for airborne use is presented in Figure 7.

In addition to the many different 1553 system configurations that the ICS might assume, it could be thought of as a prime candidate for the new technology of fiber-optic multiplexing. Due to the bus transmission rates attainable with a fiberoptic bus (around 20 mHz) and the limitations apparent in the number of stubs, audio mulitplexing represents one of many systems that could be easily integrated using this multiplexing technique.

SUMMARY AND CONCLUSION

The challenge of developing a practical audio multiplexing system using MIL-STD-1553 formats is addressed by AiResearch in the design, development, fabrication, and test of the ICS demonstration system for the Naval Air Development Center. AiResearch defined a system configuration, developed the requirements, and resolved audio processing and communication tradeoffs. AiResearch also produced operational development hardware that provides a baseline for future ICS configurations.

The AiResearch audio multiplexing system represents the first step toward the development of operational audio multiplexing systems. These would take into account the advantages of reducing station size, weight, and power requirements by using LSI and hybrid devices.

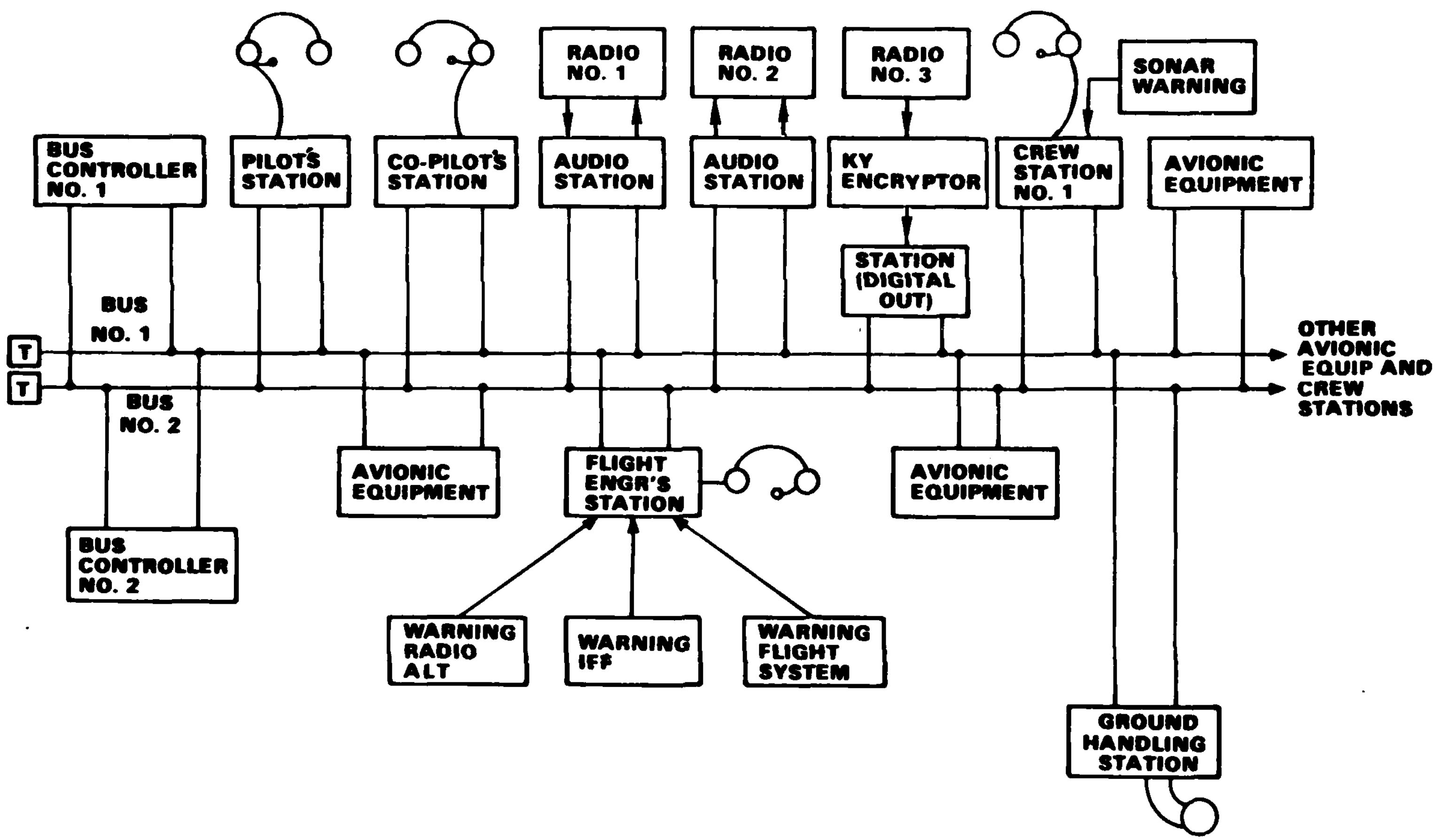

Figure 7. A Possible Future Configuration

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